

Appendix J: Climate impacts and adaptation actions for tiger salamander

The Washington-British Columbia Transboundary Climate-Connectivity Project engaged science-management partnerships to identify potential climate impacts on wildlife habitat connectivity and adaptation actions for addressing these impacts in the transboundary region of Washington and British Columbia.¹ Project partners focused their assessment on a suite of case study species, a vegetation system, and a region chosen for their shared priority status among project partners, representation of diverse habitat types and climate sensitivities, and data availability. This appendix describes potential climate impacts and adaptation actions identified for the tiger salamander (*Ambystoma tigrinum*).



Figure J.1. Tiger salamander.

In the Washington-British Columbia transboundary region, the tiger salamander primarily occupies arid grassland, shrub-steppe, and open forest habitats near water bodies lacking predatory fish.² Tiger salamanders are local migrants, dispersing up to several kilometers between breeding ponds and other ponds or upland foraging and hibernation sites.² Desiccation risk constrains dispersal among populations, with migratory movement dependent on rainfall.² Key barriers to tiger salamander movement within the transboundary region include roads, residential development, and water bodies containing predatory fish (Appendix J.1).²

Future climate change may present additional challenges and needs for tiger salamander habitat connectivity.³⁻⁴ First, climate change may impact tiger salamander core habitat and dispersal corridors in ways that may make them more or less permeable to movement. Second, existing tiger salamander core habitat and corridors may be distributed on the landscape in ways that make them more or less able to accommodate climate-driven shifts in tiger salamander distributions. For such reasons, connectivity enhancement has become the most frequently recommended climate adaptation strategy for biodiversity conservation.⁵ However, little work has been done to translate this broad strategy into specific, on-the-ground actions. Furthermore, to our knowledge, no previous work has identified specific climate impacts or adaptation responses for tiger salamander habitat connectivity. To address these needs, we describe here a novel effort to identify and address potential climate impacts on tiger salamander habitat connectivity in the transboundary region of Washington and British Columbia.

Potential climate impacts on habitat connectivity

To identify potential climate impacts on transboundary tiger salamander habitat connectivity, project partners created a conceptual model that identifies the key landscape features and processes expected to influence tiger salamander habitat connectivity, which of those are expected to be influenced by climate, and how (Appendix J.2). Simplifying complex ecological systems in such a way can make it easier to identify specific climate impacts and adaptation actions. For this reason, conceptual models have been promoted as useful adaptation tools, and have been applied in a variety of other systems.⁶ The tiger salamander conceptual model was developed using peer-reviewed articles and reports, project

¹ This report is Appendix J of the Washington-British Columbia Transboundary Climate-Connectivity Project; for more information about the project's rationale, partners, methods, and results, see Krosby et al. (2016).¹

participant expertise, and review by species experts. That said, the resulting model is intentionally simplified, and should not be interpreted to represent a comprehensive assessment of the full suite of landscape features and processes contributing to tiger salamander habitat connectivity.

Project participants used the conceptual model in conjunction with maps of projected future changes in species distributions, vegetation communities, and relevant climate variables to identify potential impacts on tiger salamander connectivity. Because a key project goal was to increase practitioner partners' capacity to access, interpret, and apply existing climate and connectivity models to their decision-making, we relied on a few primary datasets that are freely available, span all or part of the transboundary region, and reflect the expertise of project science partners. These sources include habitat connectivity models produced by the Washington Connected Landscapes Project,^{2,7} future climate projections from the Integrated Scenarios of the Pacific Northwest Environment⁸ and the Pacific Climate Impacts Consortium's Regional Analysis Tool,⁹ and models of projected range shifts and vegetation change produced as part of the Pacific Northwest Climate Change Vulnerability Assessment.¹⁰

Key impacts on transboundary tiger salamander habitat connectivity identified via this approach include changes in areas of tiger salamander climatic suitability, changes in vegetation, and changes in pond hydrology.

Changes in areas of climatic suitability

Climate change may impact tiger salamander habitat connectivity by changing the extent and location of areas of climatic suitability for tiger salamander; this may render some existing core habitat areas and corridors unsuitable for tiger salamander, and/or create new areas of suitability. Climatic niche models provide estimates of species' current and projected future areas of climatic suitability, and are available for the tiger salamander for the 2080s based on two CMIP3 Global Circulation Models (GCMs) (CGCM3.1 and UKMO-HadCM3ⁱⁱ) under the A2 (high) carbon emissions scenarioⁱⁱⁱ (Appendix J.3).

The tiger salamander's range within the transboundary study area is generally restricted to low elevation areas of the Columbia Plateau and Okanagan Valley. Climatic niche models (CNM) for the 2080s project that these areas will remain climatically suitable for tiger salamander, and that climatic suitability increases in higher elevation areas adjacent to the Okanagan Valley. Expansion is extensive under the UKMO-HadCM3 scenario, and slight under the CGCM3.1(T47) scenario. Whether tiger salamander is able to expand its range into newly climatically suitable upland locations will depend on upland availability of suitable soils for burrowing and wetlands for reproduction. In addition, the tiger salamander has limited dispersal capacity, which may restrict its ability to reach newly suitable habitat locations.

ⁱⁱ CGCM3.1(T47) and UKMO-HadCM3 are two Global Circulation Models (GCMs) which each project different potential future climate scenarios. The UKMO-HadCM3 model projects a much hotter and drier summer, while the CGCM3.1(T47) projects greater precipitation increases in spring, summer and fall. For these reasons, the UKMO-HadCM3 could be considered a "hot-dry" future, while the CGCM3.1(T47) could be considered a "warm-wet" future within the Pacific Northwest.

ⁱⁱⁱ Emissions scenarios were developed by climate modeling centers for use in modeling global and regional climate-related effects. A2 is a high, "business as usual" scenario in which emissions of greenhouse gases continue to rise until the end of the 21st century, and atmospheric CO₂ concentrations more than triple by 2100 relative to pre-industrial levels.

There are three main clusters of tiger salamander core habitat areas and corridors located on the Washington side of the transboundary region. They include, from north to south: 1) in the upper Okanagan Valley, 2) in the lower Methow Valley, and 3) in southern Stevens County (Appendix J.3). According to climatic niche models, all three clusters are projected to remain climatically suitable (stable) under the UKMO-HadCM3 climate scenario (a hot-dry future). In contrast, under the CGCM3.1(T47) climate scenario (a warm-wet future), the area surrounding the southern Stevens County cluster is projected to decline in climatic suitability, and projected suitability for the region surrounding the lower Methow Valley is mixed, with some contraction, some expansion, and some stability. These results suggests that some parts of the tiger salamander connectivity network may be on the borderline of future climatic suitability, but that there is considerable uncertainty for these areas as well.

Changes in vegetation

The tiger salamander utilizes shrub steppe and grassland habitats, particularly for dispersal in upland areas. Changes in the distribution and quality of these habitats in the transboundary region could therefore be expected to affect tiger salamander habitat connectivity.

Two types of models are available that estimate future changes in vegetation for the transboundary region: climatic niche models and mechanistic models (Appendix J.4).^{iv} Both types of models are based on results from two CMIP3 global circulation models (CGCM3.1 and Hadley CM3)ⁱⁱ under the A2 (high) emissions scenario.ⁱⁱⁱ While climatic niche vegetation models project that the Okanagan Valley will remain climatically suitable for shrub and grassland habitats, mechanistic vegetation models project that forest may encroach upon the Okanagan Valley under some climate scenarios (Appendix J.4). Such encroachment would likely negatively affect tiger salamander habitat connectivity.

Changes in pond hydrology

Tiger salamanders rely on ponds for breeding. Whether a pond provides good breeding habitat in any given year depends on both the pond's characteristics (e.g., size, depth, and soil conditions) and climatic conditions (e.g., temperature, precipitation, and evapotranspiration). To reproduce successfully, tiger salamanders need ponds with water persisting into July and August. Deep ponds are more likely to persist into the summer, and can provide a critical reproductive resource in dry years. However, deep ponds also harbor predatory fish, reducing their habitat value. Shallow ponds often do not support fish populations, but increasing temperatures may reduce their quality as breeding habitats. Declines in the number of high quality breeding ponds and increased distances among remaining ponds would reduce tiger salamander habitat connectivity. In addition, the loss of some ponds could have a disproportionate impact on connectivity if they provide critical links in the pond network.

Climate change may have significant impacts on pond hydrology and persistence in the transboundary region. Climate models project that spring precipitation will increase (Appendix J.5: Spring Precipitation), but that summer precipitation (Appendix J.5: Summer Precipitation) and spring and summer runoff will decrease (Appendix J.5: Spring Runoff; Summer Runoff), reducing water availability to fill ponds.

^{iv} Climatic niche vegetation models mathematically define the climatic conditions within a given vegetation type's current distribution and then project where on the landscape those conditions are expected to occur in the future. These models do not incorporate other important factors that determine vegetation such as soil suitability, dispersal, competition, and fire. In contrast, mechanistic vegetation models do incorporate these ecological processes as well as projected climate changes and potential effects of carbon dioxide fertilization. However, mechanistic models only projected changes to very general vegetation types such as cold forest, shrub steppe, or grassland.

Projected declines in snowpack (Appendix J.5: Spring (April 1st) Snowpack) may also reduce the amount of runoff available from snowmelt during spring and summer. Spring evapotranspiration is projected to increase (Appendix J.5: Evapotranspiration, March-May), but summer evapotranspiration is projected to decrease or stay the same at low to mid elevations (Appendix J.5: Evapotranspiration, July-September). A decrease in evapotranspiration means that water evaporates more slowly, theoretically leaving more water in ponds. The net impacts of these changes are difficult to predict, although according to the CNMs these projected changes are generally not outside the range of conditions that tiger salamander experience within their current range.

In agreement with the climatic niche model projections, climate projections for summer runoff and evapotranspiration suggest that the lower Methow and southern Stevens County clusters are more at risk than the upper Okanogan Valley cluster. For the lower Methow and southern Stevens County clusters, summer runoff decreases and summer evapotranspiration either increases slightly (creating drier conditions) or remains roughly the same. However, the upper Okanogan Valley cluster, summer runoff stays the same or increases and summer evapotranspiration decreases, leading to generally wetter conditions in this region.

Changes in desiccation risk

Tiger salamanders disperse up to several kilometers between breeding ponds and other ponds or upland foraging and hibernation sites.² Desiccation risk constrains dispersal among populations, with migratory movement dependent on rainfall.² Projected increases in temperatures (Appendix J.5: Increase in Average Annual Daytime Temperature) and decreases in summer precipitation (Appendix J.5: Summer Precipitation) and soil moisture (Appendix J.5: Summer Soil Moisture) may increase desiccation risk during dispersal, reducing tiger salamander habitat connectivity. These impacts may be greatest in upland habitats where future increases in drying may be more severe.

Adaptation responses

After identifying potential climate impacts on tiger salamander habitat connectivity, project participants used conceptual models to identify which relevant landscape features or processes could be affected by management activities, and subsequently what actions could be taken to address projected climate impacts (Appendix J.2). Key adaptation actions identified by this approach fall under three main categories: those that address potential climate impacts on tiger salamander habitat connectivity, those that address novel habitat connectivity needs for promoting climate-induced shifts in tiger salamander distributions, and those that identify spatial priorities for implementation.

Addressing climate impacts on tiger salamander habitat connectivity

Actions to address climate impacts on pond quality include:

- Restoring and/or protecting riparian vegetation to shade ponds, which would reduce water temperatures and evaporation rates.
- Excluding cattle from ponds and surrounding vegetation (e.g., by installing fencing), and using techniques (e.g., fabric and gravel installation) to prevent cattle from leaving pockmarks, which reduce pond quality.
- Protecting and/or reintroducing beavers into watersheds, which may improve wetland quality and connectivity.

- Widening ponds to increase access for salamanders and/or deepening ponds to increase pond persistence into summer (while maintaining slope to allow salamander access).
- Adding water and removing predatory fish from targeted ponds. Because this strategy would be highly resource intensive it should be considered an emergency measure to be implemented only if necessary.
- Establishing retention ponds in urban areas, which would mitigate increased flooding in winter and spring while also increasing available tiger salamander habitat. These areas could be treated as managed wetlands.
- Diverting rainwater into existing tiger salamander ponds. This option should be carefully considered in light of possible chemical run-off and turbidity issues.

Actions to address climate impacts on tiger salamander dispersal habitat include:

- Monitoring vegetation within movement corridors and managing it to maintain structure that facilitates movement. Retention of coarse woody debris and plant cover to minimize desiccation is particularly important.
- Avoiding development of new roads through existing or potential future movement corridors. If roads are present, consider installing underpasses or retrofitting culverts to facilitate safe crossings for salamanders.

Enhancing connectivity to facilitate range shifts

Actions that may help tiger salamander adjust its range to track shifts in areas of climatic suitability include:

- Maintaining and restoring corridors that span elevation and climatic gradients (e.g., climate-gradient corridors⁷ (Appendix J.1)), to ensure that tiger salamanders have the ability to disperse into higher elevation areas projected to become newly climatically suitable (Appendix J.3).
- Maintaining and restoring corridors between areas of declining climatic suitability and areas of stability or increasing suitability (Appendix J.3).

Spatial priorities for implementation

Spatial priorities for implementation of the adaptation actions described above include:

- Existing tiger salamander core habitat areas and corridors (Appendix J.1), which will be important for maintaining tiger salamander populations under current climate, and facilitating tiger salamander response to future change. Tiger salamander linkage network pinch-points, barriers and restoration opportunities, and areas of high network centrality all offer potential priority areas for implementation.²
- Ponds that are deep, free of predatory fish, and located in cooler and/or wetter micro-climates. These may be more likely to maintain suitable breeding habitat under future changes in climate.
- The Okanagan Valley, which is a priority area for tiger salamander habitat in British Columbia.

Policy considerations and research needs

Land and water use planning

Actions for addressing climate impacts on tiger salamander connectivity through land and water use planning include:

- Carefully reviewing water permit requests affecting tiger salamander ponds that are not currently allocated for irrigation withdrawals. Consider not permitting new licenses for known tiger salamander ponds, or, if licenses exist, ensure that volume removal limits are enforced.
- Securing water rights to maintain moisture in ponds as well as riparian areas that provide shade to ponds.
- Incorporating these adaptation strategies into the management of conservation areas, by working with governments, First Nations, tribes, NGOs, and other partners.
- Reviewing and implementing existing guidance and plans relating to tiger salamander habitat management. Evaluate existing recommendations for opportunities to address climate impacts.

Additional Research

Future research that could help inform tiger salamander habitat connectivity conservation under climate change includes:

- Developing transboundary tiger salamander connectivity models. Existing models are available only for Washington State (Appendix J.1).
- Evaluating the extent to which areas projected to become climatically suitable for tiger salamander include suitable soils, ponds, and vegetation.
- Identifying climate-resilient ponds. Climate resilient ponds are those that are most likely to maintain high quality breeding habitat regardless of future climatic changes. These could be ponds that are unlikely to dry out even under extreme climate change scenarios, either because they are deep enough or because ground water conditions help maintain ponds levels. Ponds located in areas with cooler microclimates, due to topography or aspect, may also be more resilient to warming; overlaying maps of breeding ponds with maps of heat load index, which estimates potential incident solar radiation based on topographic conditions such as slope and aspect,¹¹ could help identify these ponds. Recent studies evaluating climate resilience of ponds and wetlands may offer useful starting points for future, transboundary analysis.¹²⁻¹³
- Identifying corridors between locations with projected declines in climatic suitability and areas with projected stable or improving climatic suitability. Use climatic niche models (Appendix J.3) and vegetation projections (Appendix J.4) to identify potentially stable or improving locations. Use corridor models (Appendix J.1) and/or conduct new modeling to identify potential corridors for connecting vulnerable tiger salamander core habitat areas to areas projected to remain climatically suitable or become newly suitable.

References

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2. Washington Wildlife Habitat Connectivity Working Group. 2012. Washington Connected Landscapes Project: Analysis of the Columbia Plateau Ecoregion. Washington's Department of Fish and Wildlife, and Department of Transportation, Olympia, WA.
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Glossary of Terms

Assisted migration – Species and populations are deliberately planted or transported to new suitable habitat locations, typically in response to declines in historic habitat quality resulting from rapid environmental change, principally climate change.

Centrality — Refers to a group of landscape metrics that rank the importance of habitat patches or linkages in providing movement across an entire network, i.e., as “gatekeepers” of flow across a landscape.^v

Connectivity — Most commonly defined as the degree to which the landscape facilitates or impedes movement among resource patches.^{vi} Can be important for maintaining ecological, population-level, or evolutionary processes.

Core Areas — Large blocks (10,000+ acres) of contiguous lands with relatively high landscape permeability.

Corridor — Refers to modeled movement routes or physical linear features on the landscape (e.g., continuous strips of riparian vegetation or transportation routes). In this document, the term “corridor” is most often used in the context of modeled least-cost corridors, i.e., the most efficient movement pathways for wildlife and ecological processes that connect HCAs or core areas. These are areas predicted to be important for migration, dispersal, or gene flow, or for shifting ranges in response to climate change and other factors affecting the distribution of habitat.

Desiccation – Extreme water deprivation, or process of extreme drying.

Dispersal — Relatively permanent movement of an individual from an area, such as movement of a juvenile away from its place of birth.

Fracture Zone — An area of reduced permeability between core areas. Most fracture zones need significant restoration to function as reliable linkages. Portions of a fracture zone may be potential linkage zones.

Habitat Connectivity — See Connectivity.

Landscape Connectivity — See Connectivity.

Permeability — The ability of a landscape to support movement of plants, animals, or processes.

^v Carroll, C. 2010. Connectivity analysis toolkit user manual. Version 1.1. Klamath Center for Conservation Research, Orleans, California. Available at www.connectivitytools.org (accessed January 2016).

^{vi} Taylor, P. D., L. Fahrig, K. Henein, and G. Merriam. 1993. Connectivity is a vital element of landscape structure. *Oikos* 68: 571-573.

Pinch point — Portion of the landscape where movement is funneled through a narrow area. Pinch points can make linkages vulnerable to further habitat loss because the loss of a small area can sever the linkage entirely. Synonyms are bottleneck and choke point.

Refugia — Geographical areas where a population can survive through periods of unfavorable environmental conditions (e.g., climate-related effects).

Thermal barriers — Water temperatures warm enough to prevent migration of a given fish species. These barriers can prevent or delay spawning for migrating salmonids.

Appendices J.1-5

Appendices include all materials used to identify potential climate impacts on habitat connectivity for case study species, vegetation systems, and regions. For tiger salamander, these materials include:

Appendix J.1. Habitat connectivity models

Appendix J.2. Conceptual model of habitat connectivity

Appendix J.3. Climatic niche models

Appendix J.4. Projected changes in vegetation communities

Appendix J.5. Projected changes in relevant climatic variables

All maps included in these appendices are derived from a few primary datasets, chosen because they are freely available, span all or part of the transboundary region, and reflect the expertise of project science partners. These sources include habitat connectivity models produced by the Washington Connected Landscapes Project,^{2,7} future climate projections from the Integrated Scenarios of the Pacific Northwest Environment⁸ and the Pacific Climate Impacts Consortium's Regional Analysis Tool,⁹ and models of projected range shifts and vegetation change produced as part of the Pacific Northwest Climate Change Vulnerability Assessment.¹⁰

All maps are provided at three geographic extents corresponding to the distinct geographies of the three project partnerships (Fig. J.2):

- i. **Okanagan Nation Territory**, the assessment area for project partners: Okanagan Nation Alliance and its member bands and tribes, including Colville Confederated Tribes.
- ii. **The Okanagan-Kettle Region**, the assessment area for project partners: Transboundary Connectivity Working Group (i.e., the Washington Habitat Connectivity Working Group and its BC partners).
- iii. **The Washington-British Columbia Transboundary Region**, the assessment area for project partners: BC Parks; BC Forests, Lands, and Natural Resource Operations; US Forest Service; and US National Park Service.

All project reports, data layers, and associated metadata are freely available online at:

<https://nplcc.databasin.org/galleries/5a3a424b36ba4b63b10b8170ea0c915e>

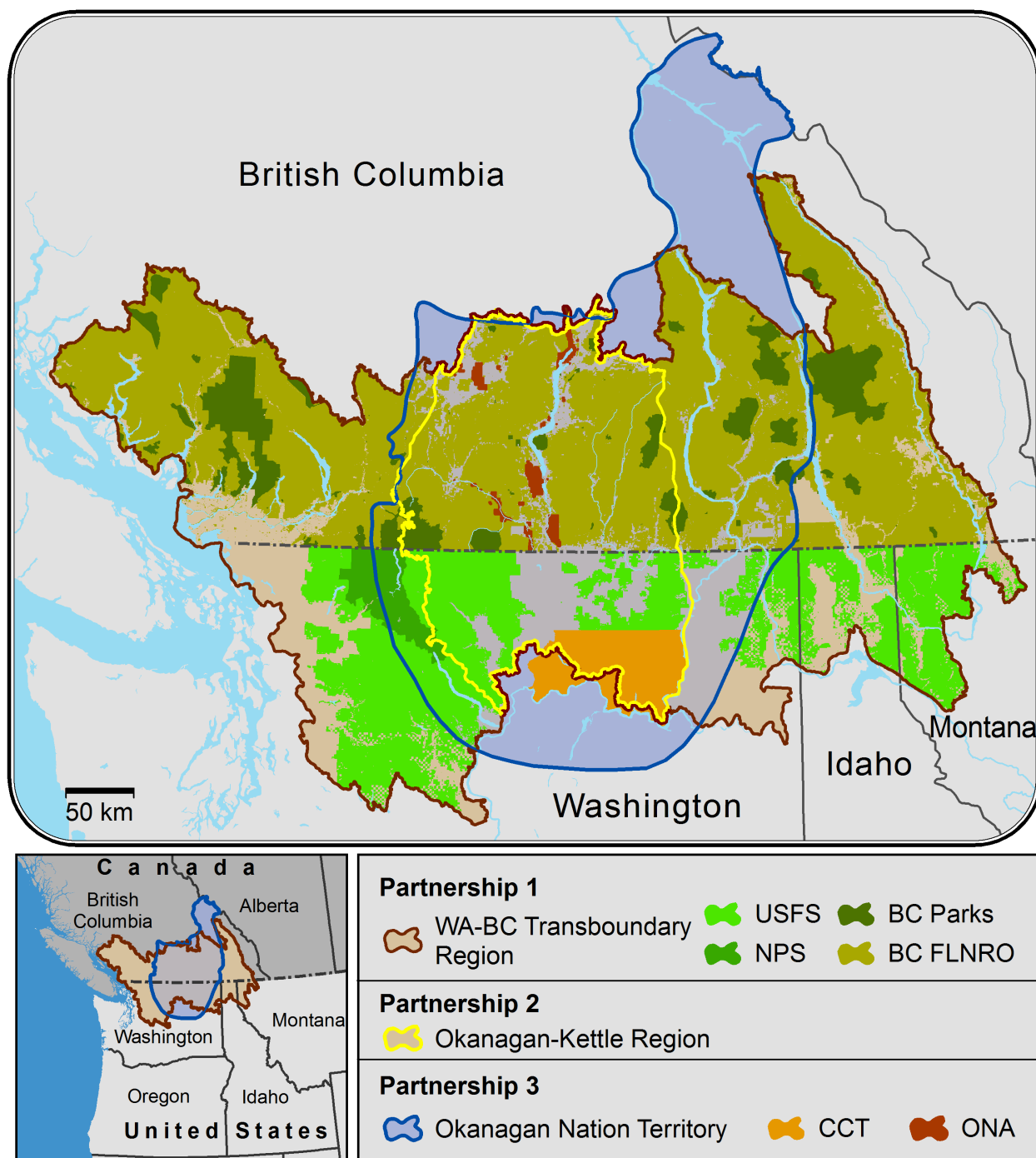


Figure J.2. Project partners and assessment areas.

Appendix J.1. Habitat Connectivity Models

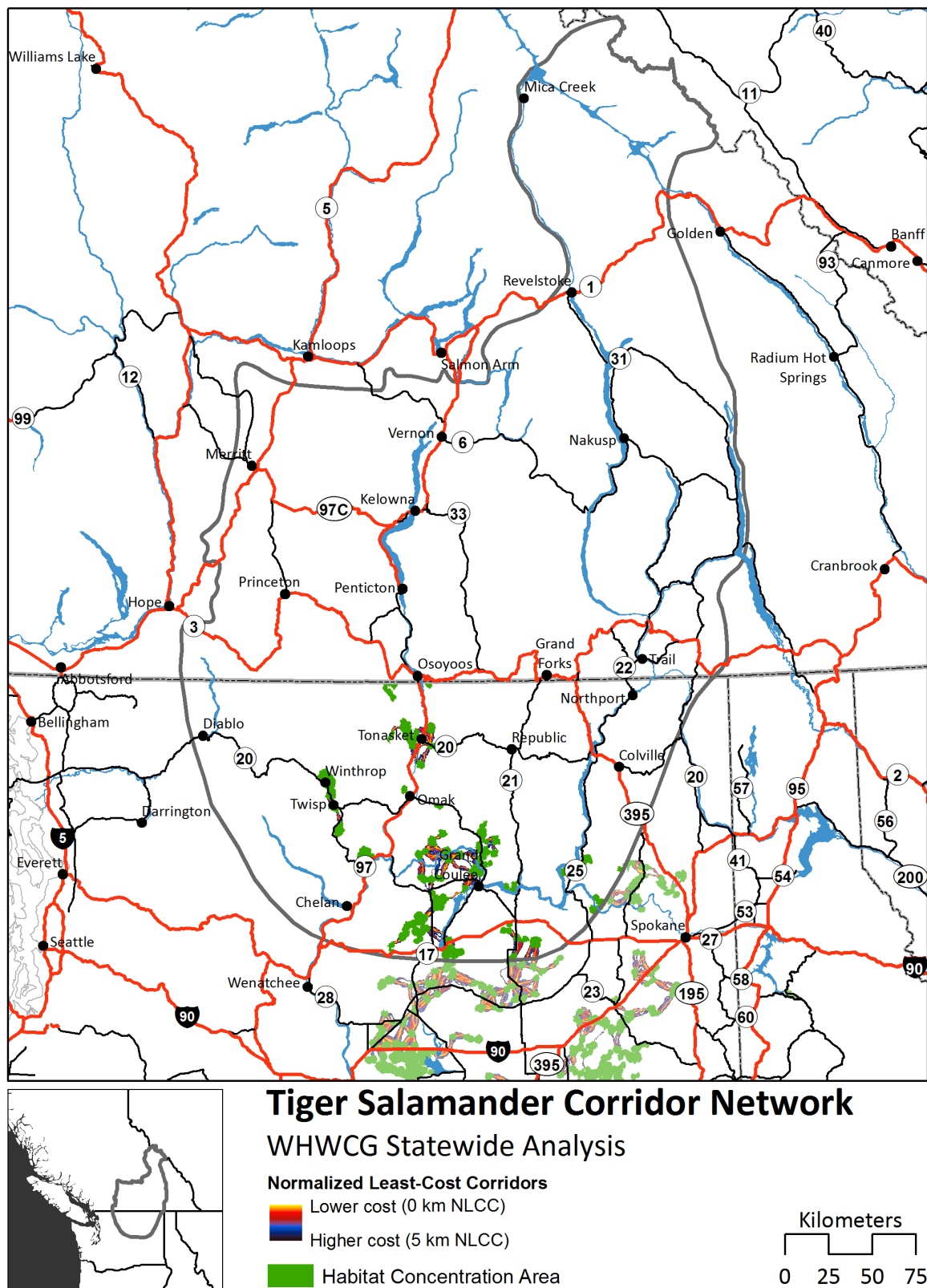
Habitat connectivity models are available from the Washington Connected Landscapes Project.^{vii} These models can be used to prioritize areas for maintaining and restoring habitat connectivity now and in the future as the climate changes. Available models include species corridor networks, landscape integrity corridor networks, and climate-gradient corridor networks. These models are available at two distinct scales (though for many species, only one scale is available or was selected for use by project participants): 1) **WHCWG Statewide** models span Washington State and surrounding areas of Oregon, Idaho, and British Columbia; 2) **WHCWG Columbia Plateau** models span the Columbia Plateau ecoregion within Washington State, and do not extend into British Columbia.

- a) **WHCWG Columbia Plateau Analysis: Tiger Salamander Corridor Network.**² This map shows Habitat Concentration Areas (HCAs, green polygons), which are large, contiguous areas featuring little resistance to species movement; and corridors (glowing yellow areas) connecting HCAs, modeled using least cost corridor analysis.
- b) **WHCWG Statewide Analysis: Climate-Gradient Corridor Network (Temperature + Landscape Integrity).**⁷ This map shows corridors (glowing white areas, with resistance to movement increasing as white fades to black) connecting core habitat areas (polygons, shaded to reflect mean annual temperatures) that are of high landscape integrity (i.e., have low levels of human modification) and differ in temperature by $>1^{\circ}\text{C}$. These corridors thus allow for movement between relatively warmer and cooler core habitat areas, while avoiding areas of low landscape integrity (e.g., roads, agricultural areas, urban areas), and minimizing major changes in temperature along the way (e.g., crossing over cold peaks or dipping into warm valleys). The northern extent of this analysis falls just north of Kamloops, BC.

^{vii} For detailed methodology and data layers see <http://www.waconnected.org>.

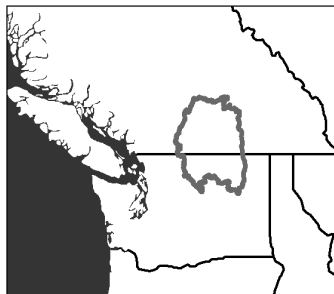
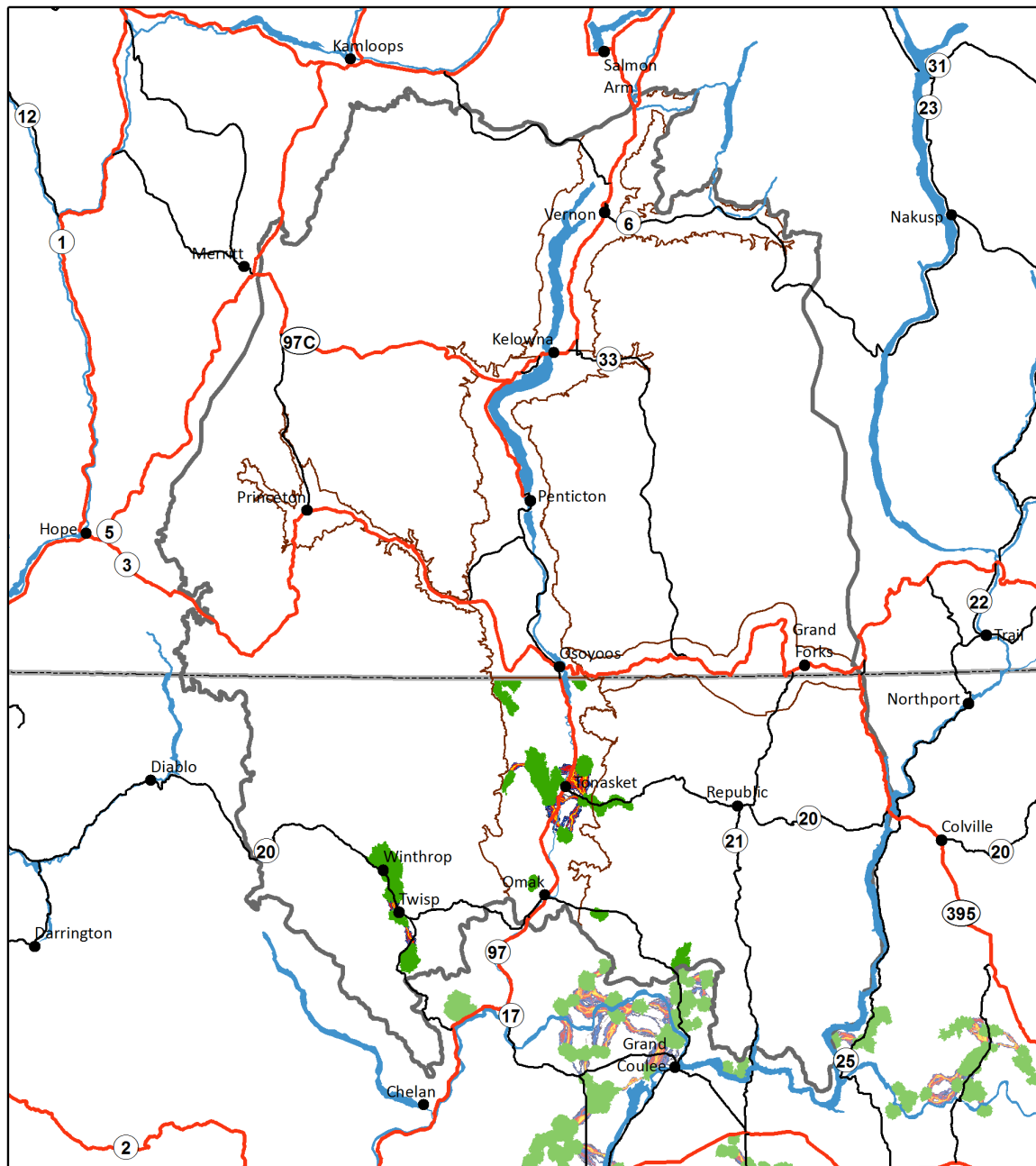
Appendix J.1a. WHCWG Columbia Plateau: Tiger Salamander Corridor Model

i) Extent: Okanagan Nation Territory






Appendix J.1a. WHCWG Columbia Plateau: Tiger Salamander Corridor Model

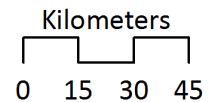
ii) Extent: Okanagan-Kettle Region



Tiger Salamander Corridor Network WHCWG Statewide Analysis

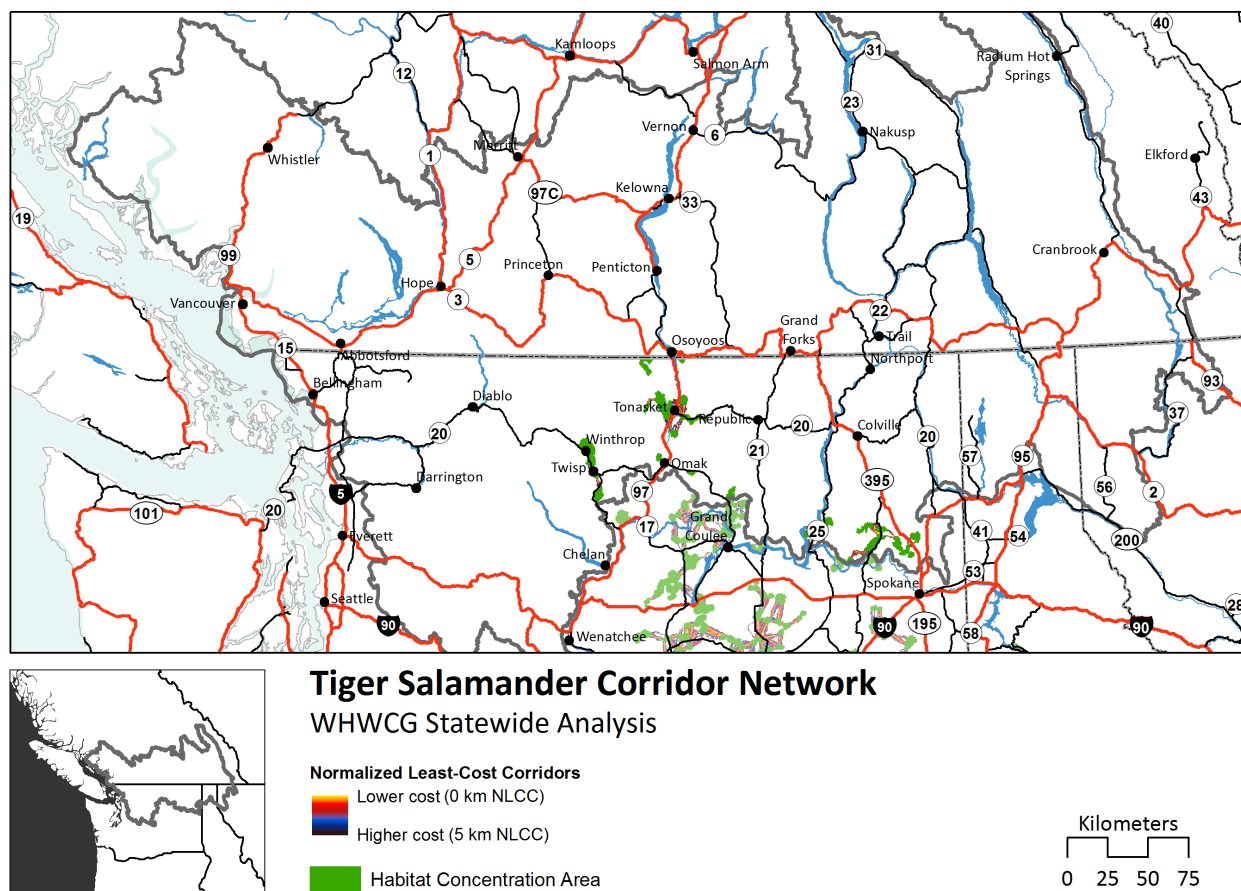
Normalized Least-Cost Corridors

-  Lower cost (0 km NLCC)
-  Higher cost (5 km NLCC)
-  Habitat Concentration Area



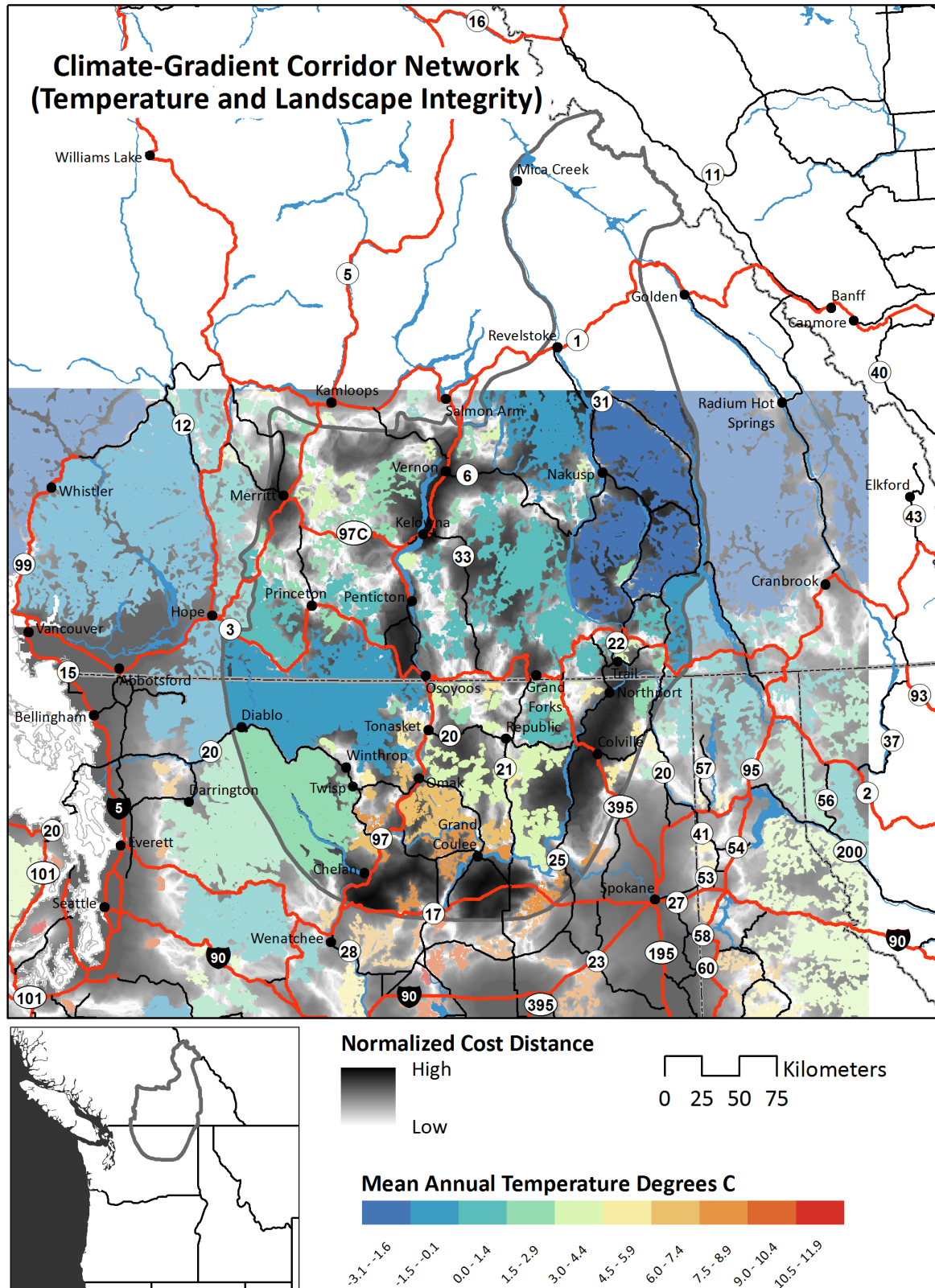
Appendix J.1a. WHCWG Columbia Plateau: Tiger Salamander Corridor Model

iii) Extent: Washington-British Columbia Transboundary Region



Appendix J.1b. WHCWG Statewide Analysis: Climate-Gradient Corridor Network (Temperature + Landscape Integrity)

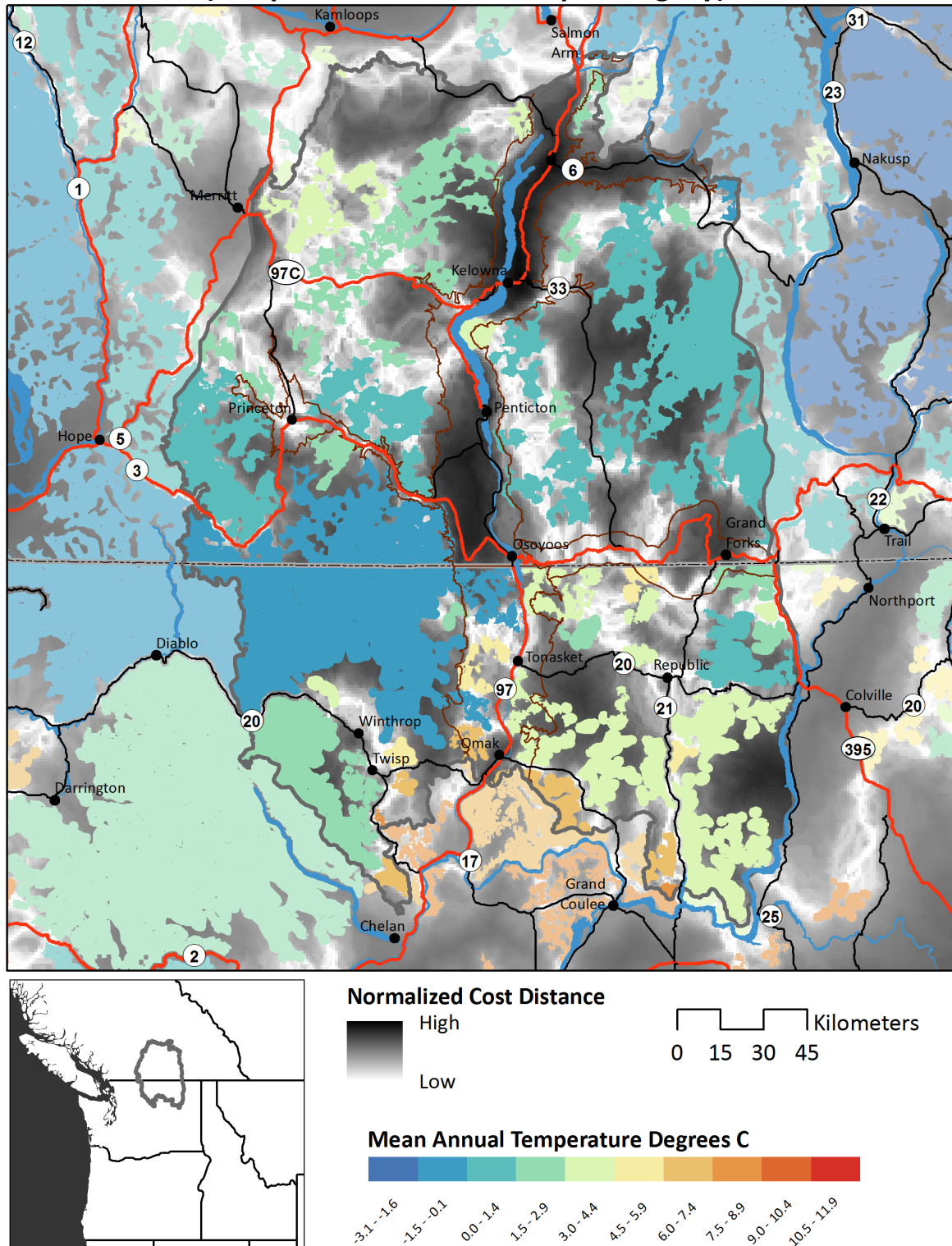
i) Extent: Okanagan Nation Territory



Appendix J.1b. WHCWG Statewide Analysis: Climate-Gradient Corridor Network (Temperature + Landscape Integrity)

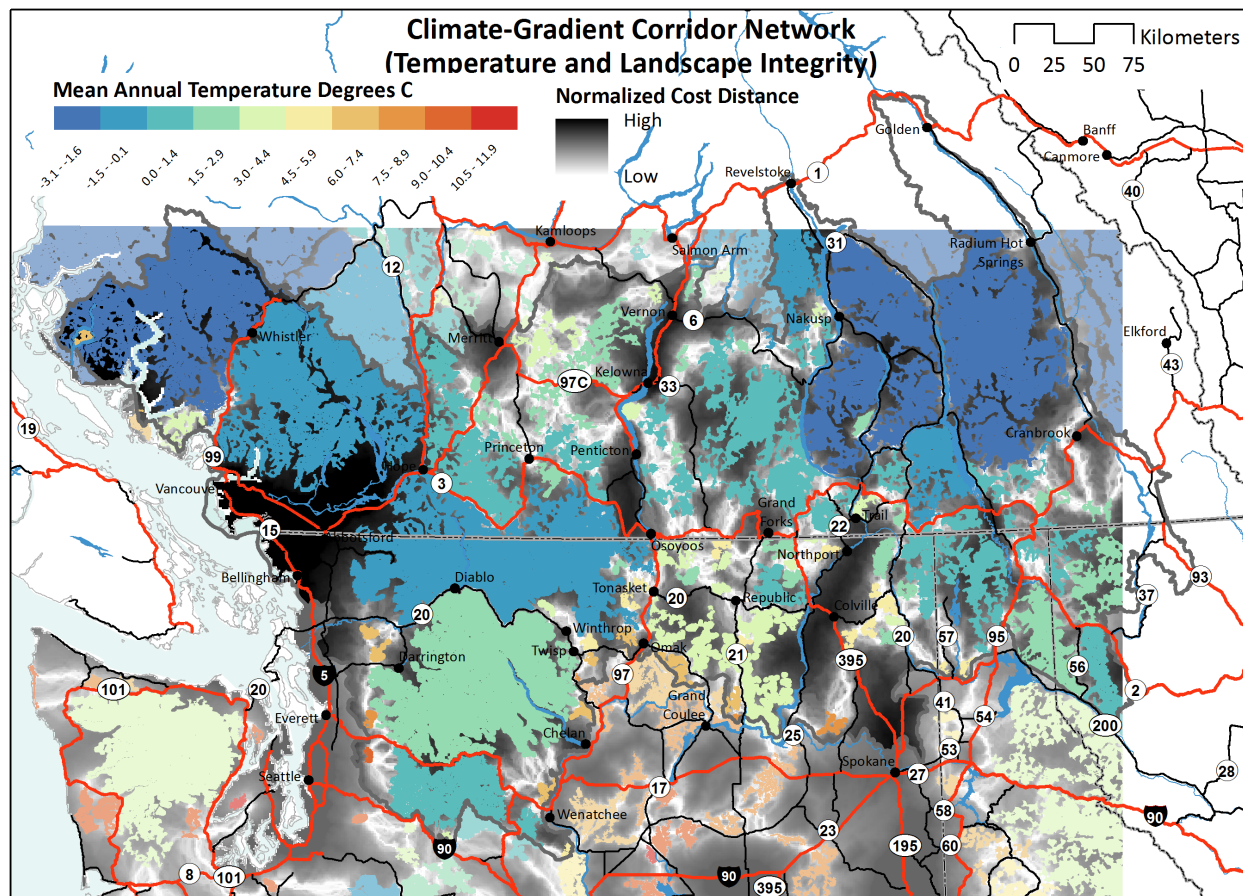
ii) Extent: Okanagan-Kettle Region

**Climate-Gradient Corridor Network
(Temperature and Landscape Integrity)**



Appendix J.1b. WHCWG Statewide Analysis: Climate-Gradient Corridor Network (Temperature + Landscape Integrity)

iii) Extent: Washington-British Columbia Transboundary Region



Appendix J.2. Conceptual Model of Habitat Connectivity

To identify potential climate impacts on transboundary tiger salamander habitat connectivity, project partners created a conceptual model that identifies the key landscape features and processes expected to influence tiger salamander habitat connectivity, which of those are expected to be influenced by climate, and how. Simplifying complex ecological systems in such a way can make it easier to identify specific climate impacts and adaptation actions. For this reason, conceptual models have been promoted as useful adaptation tools, and have been applied in a variety of other systems.⁶ The tiger salamander conceptual model was developed using peer-reviewed articles and reports, project participant expertise, and review by species experts. That said, the resulting model is intentionally simplified, and should not be interpreted to represent a comprehensive assessment of the full suite of landscape features and processes contributing to tiger salamander habitat connectivity.

Conceptual models illustrate the relationships between the key landscape features (white boxes), ecological processes (rounded corner purple boxes), and human activities (rounded corner blue boxes) that influence the quality and permeability of core habitat and dispersal habitat for a given species. Climatic variables for which data on projected changes are available are highlighted with a yellow outline. Green arrows indicate a positive correlation between linked variables (i.e., as variable x increases variable y increases); note that a positive correlation is not necessarily beneficial to the species. Red arrows indicate a negative relationship between variables (i.e., as variable x increases, variable y decreases); again, negative correlations are not necessarily harmful to the species.

Expert reviewers for the tiger salamander conceptual model included:

- Orville Dyer, BC FLNRO
- Mike Sarall, Ophiuchus Consulting
- Alison Peatt, RPBio, Environmental Planner for South Okanagan-Similkameen Communities
- Tory Stevens, BC Parks
- Okanagan Nation Alliance (staff herpetologist)

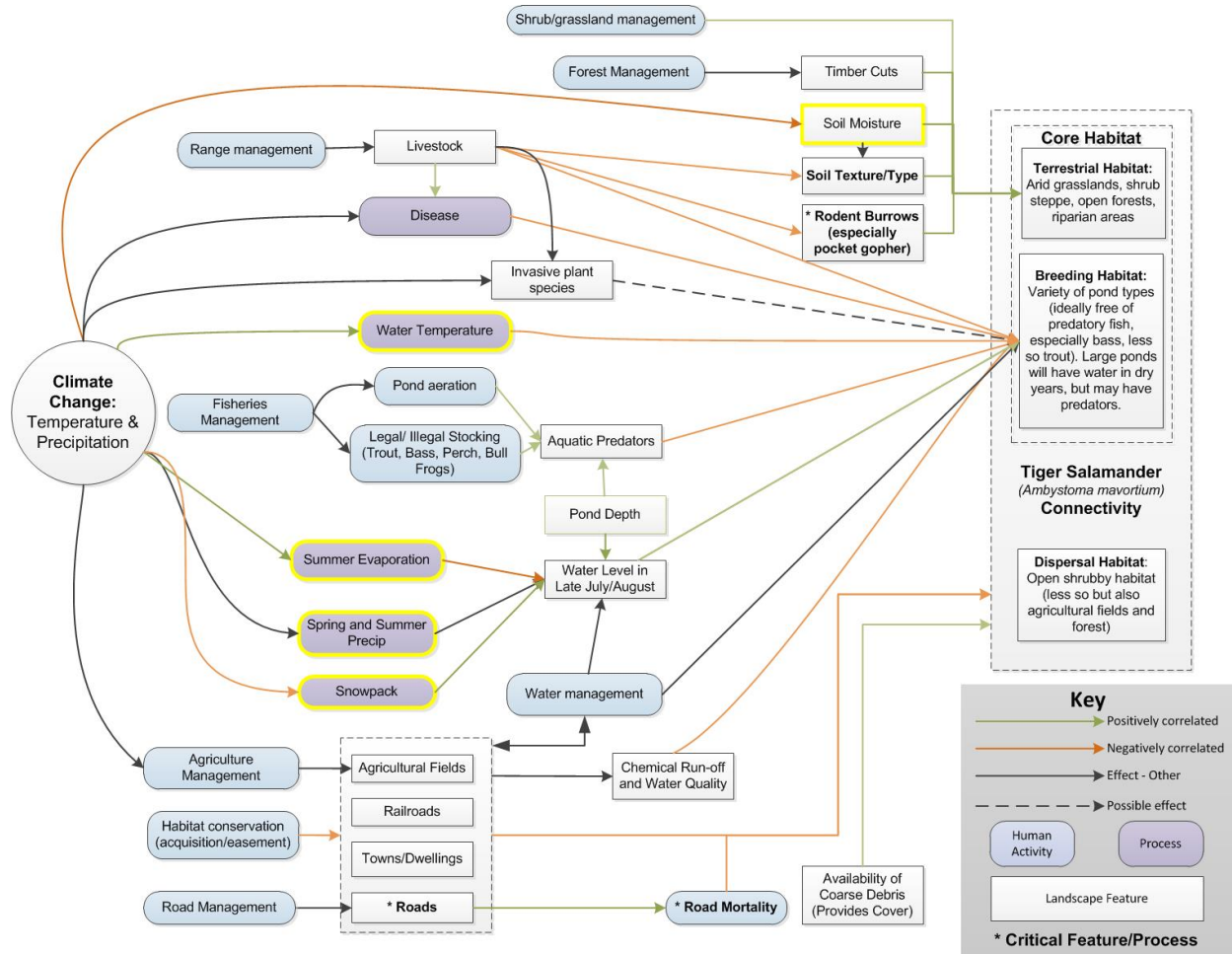
Key references used to create the tiger salamander conceptual model included:

McMenamin, S. K., Hadly, E. A., & Wright, C. K. (2008). Climatic change and wetland desiccation cause amphibian decline in Yellowstone National Park. *Proceedings of the national Academy of Sciences*, 105(44), 16988-16993

Washington Wildlife Habitat Connectivity Working Group (WHCWG). 2012. Washington Connected Landscapes Project: Analysis of the Columbia Plateau Ecoregion. Washington's Department of Fish and Wildlife, and Department of Transportation, Olympia, WA.

IUCN. 2015. *Ambystoma tigrinum*. <http://www.iucnredlist.org/details/83293207/0>. Accessed on 4/28/2016.

Appendix J.2. Conceptual Model of Tiger Salamander Connectivity



Appendix J.3. Climatic Niche Models

Climatic niche models (CNM) mathematically define the climatic conditions within each species' current geographic distribution, and then apply projected climate changes to identify where on the landscape those climate conditions are projected to be located in the future. These maps show CNM results based on results from two CMIP3 Global Circulation Models (GCMs): CGCM3.1(T47) and UKMO-HadCM3.^{viii} Both models use the A2 (high) emissions scenario.^{ix} CNMs are based on climate conditions alone and do not account for dispersal ability, genetic adaptation, interspecies interactions, or other aspects of habitat suitability. Once projected range shifts were modeled, current land uses and projected vegetation types (identified using Shafer et al. 2015^x) that are unlikely to support species occurrence were removed. For example, areas currently defined as urban were removed for species unable to live in urban landscapes, and grassland habitats were removed for forest-dependent species. Both would be shown as unsuitable.

Dark gray areas indicate areas of the species' current range that are projected to remain climatically suitable by both GCMs (i.e., range is expected to remain "stable"). Dark pink areas are projected to become less climatically suitable by both GCMs (i.e., range is expected to "contract"). Light pink areas are projected to become less suitable under one model but remain stable under the other. Dark green areas are areas that are not within the species' current range but are projected to become climatically suitable by both GCMs (i.e., the range is expected to "expand"). Light green areas are projected to become climatically suitable by one GCM, but not the other.

^{viii} CGCM3.1(T47) and UKMO-HadCM3 are two Global Circulation Models (GCMs) which each project different potential future climate scenarios. The UKMO-HadCM3 model projects a much hotter and drier summer, while the CGCM3.1(T47) projects greater precipitation increases in spring, summer and fall. For these reasons, the UKMO-HadCM3 could be considered a "hot-dry" future, while the CGCM3.1(T47) could be considered a "warm-wet" future within the Pacific Northwest.

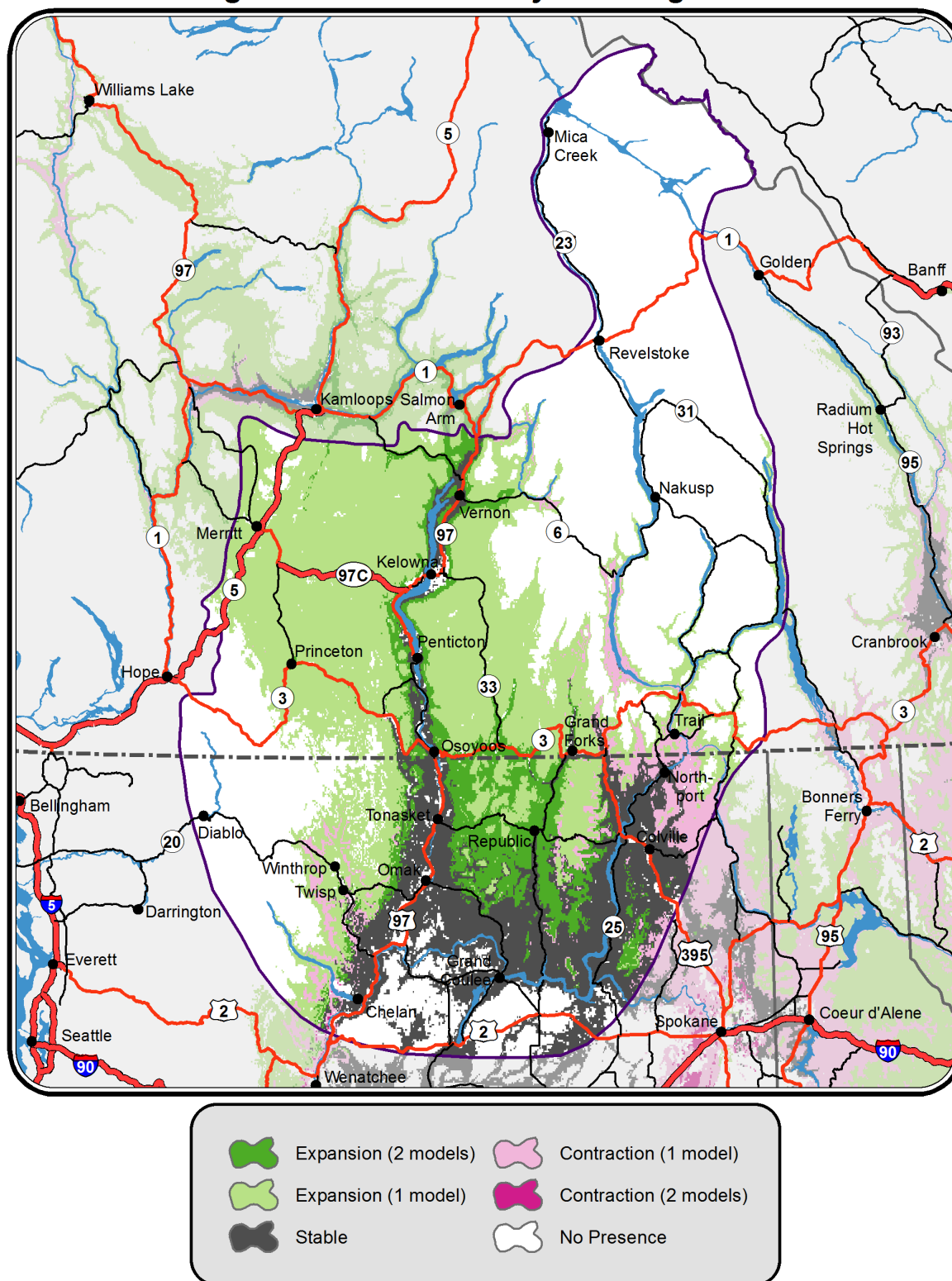
^{ix} Emissions scenarios were developed by climate modeling centers for use in modeling global and regional climate-related effects. A2 is a high, "business as usual" scenario in which emissions of greenhouse gases continue to rise until the end of the 21st century, and atmospheric CO₂ concentrations more than triple by 2100 relative to pre-industrial levels.

^x Shafer, S.L., Bartlein, P.J., Gray, E.M., and R.T. Pelltier. 2015. Projected future vegetation changes for the northwest United States and southwest Canada at a fine spatial resolution using a dynamic global vegetation model. *PLoS ONE* 10: e0138759. doi:10.1371/journal.pone.0138759

Appendix J.3. Tiger Salamander Climatic Niche Model

i) Extent: Okanagan Nation Territory

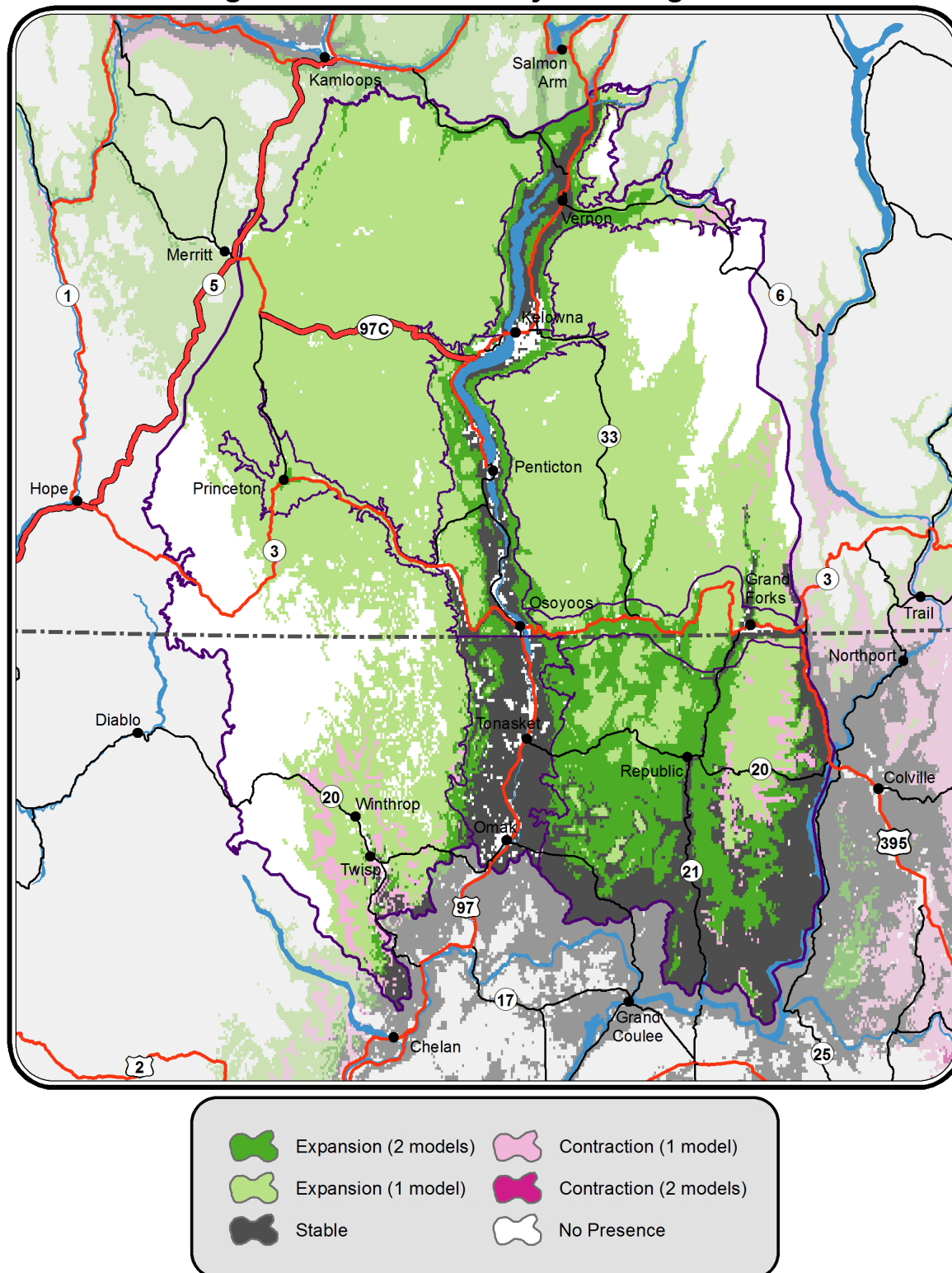
Tiger Salamander-*Ambystoma tigrinum*



Appendix J.3. Tiger Salamander Climatic Niche Model

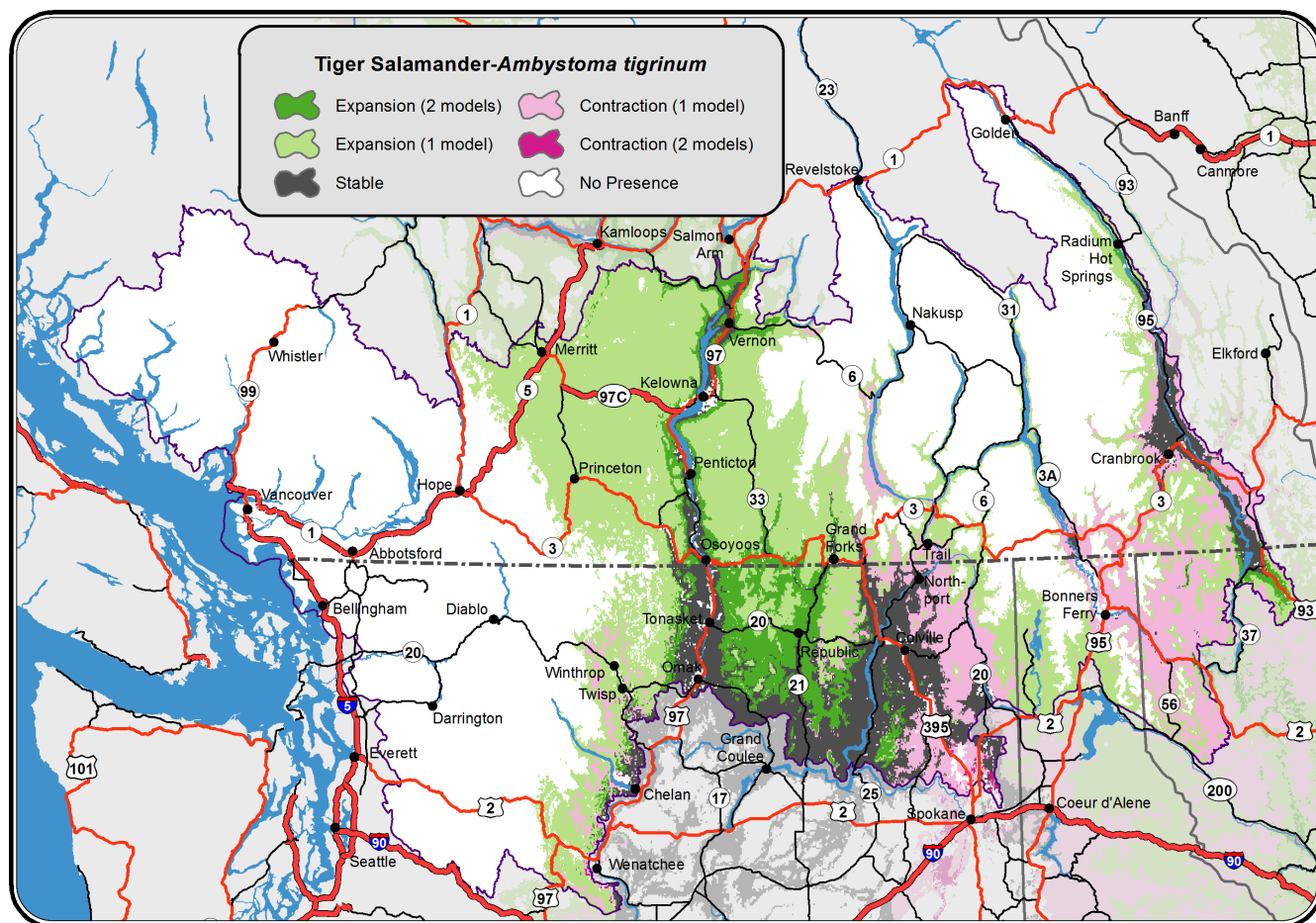
ii) Extent: Okanagan-Kettle Region

Tiger Salamander-*Ambystoma tigrinum*



Appendix J.3. Tiger Salamander Climatic Niche Model

iii) Extent: Washington-British Columbia Transboundary Region



Appendix J.4. Projected Changes in Vegetation

Two types of models are available that project future changes in vegetation that could affect a species' habitat connectivity: climatic niche models and mechanistic models. Climatic niche vegetation models mathematically define the climatic conditions within a given vegetation type's current distribution and then project where on the landscape those conditions are expected to occur in the future. These models do not incorporate other important factors that determine vegetation such as soil suitability, dispersal, competition, and fire. In contrast, mechanistic vegetation models do incorporate these ecological processes, as well as projected climate changes and the potential effects of carbon dioxide fertilization. However, mechanistic models only project changes to very general vegetation types (e.g., cold forest, shrub steppe, or grassland). Both types of models included below show vegetation model results based on results from two CMIP3 Global Circulation Models (GCMs): CGCM3.1(T47) and UKMO-HadCM3.^{xi} Both models also use the A2 (high) emissions scenario.^{xii}

- a) **Biome Climatic Niche Vegetation Model.**^{xiii} This climatic niche vegetation model shows the projected response of biomes or forest types to projected climate change.
- b) **Mechanistic Vegetation Model.**^{xiv} This mechanistic vegetation model shows simulated vegetation composition and distribution patterns under climate change.

^{xi} CGCM3.1(T47) and UKMO-HadCM3 are two Global Circulation Models (GCMs) which each project different potential future climate scenarios. The UKMO-HadCM3 model projects a much hotter and drier summer, while the CGCM3.1(T47) projects greater precipitation increases in spring, summer and fall. For these reasons, the UKMO-HadCM3 could be considered a "hot-dry" future, while the CGCM3.1(T47) could be considered a "warm-wet" future within the Pacific Northwest.

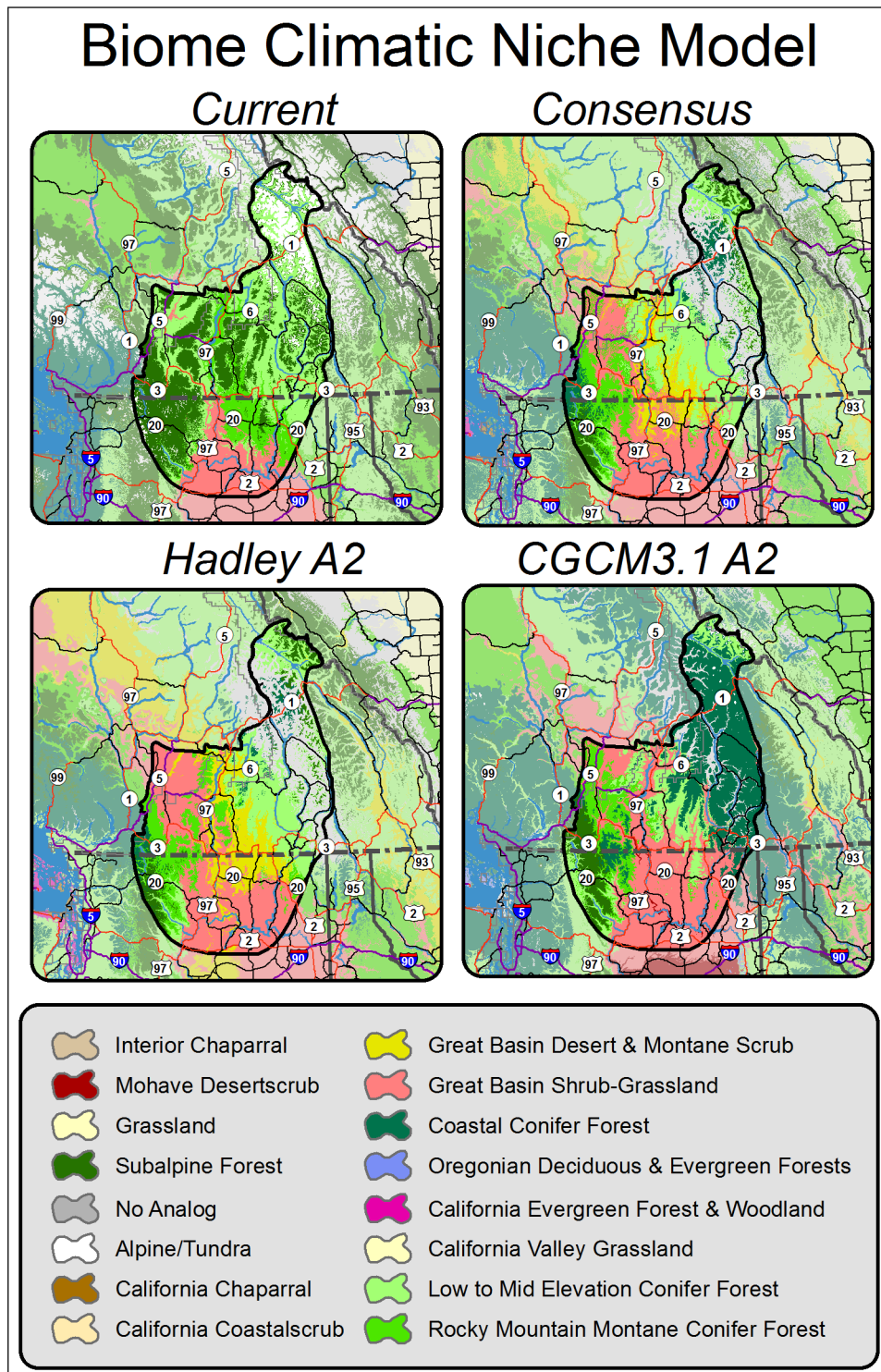
^{xii} Emissions scenarios were developed by climate modeling centers for use in modeling global and regional climate-related effects. A2 is a high, "business as usual" scenario in which emissions of greenhouse gases continue to rise until the end of the 21st century, and atmospheric CO₂ concentrations more than triple by 2100 relative to pre-industrial levels.

^{xiii} Rehfeldt, G.E., Crookston, N.L., Sáñez-Romero, C., Campbell, E.M. 2012. North American vegetation model for land-use planning in a changing climate: a solution to large classification problems. *Ecological Applications* 22: 119-141.

^{xiv} Shafer, S.L., Bartlein, P.J., Gray, E.M., and R.T. Peltier. 2015. Projected future vegetation changes for the Northwest United States and Southwest Canada at a fine spatial resolution using a dynamic global vegetation model. *PLoS ONE* 10: e0138759. doi:10.1371/journal.pone.0138759.

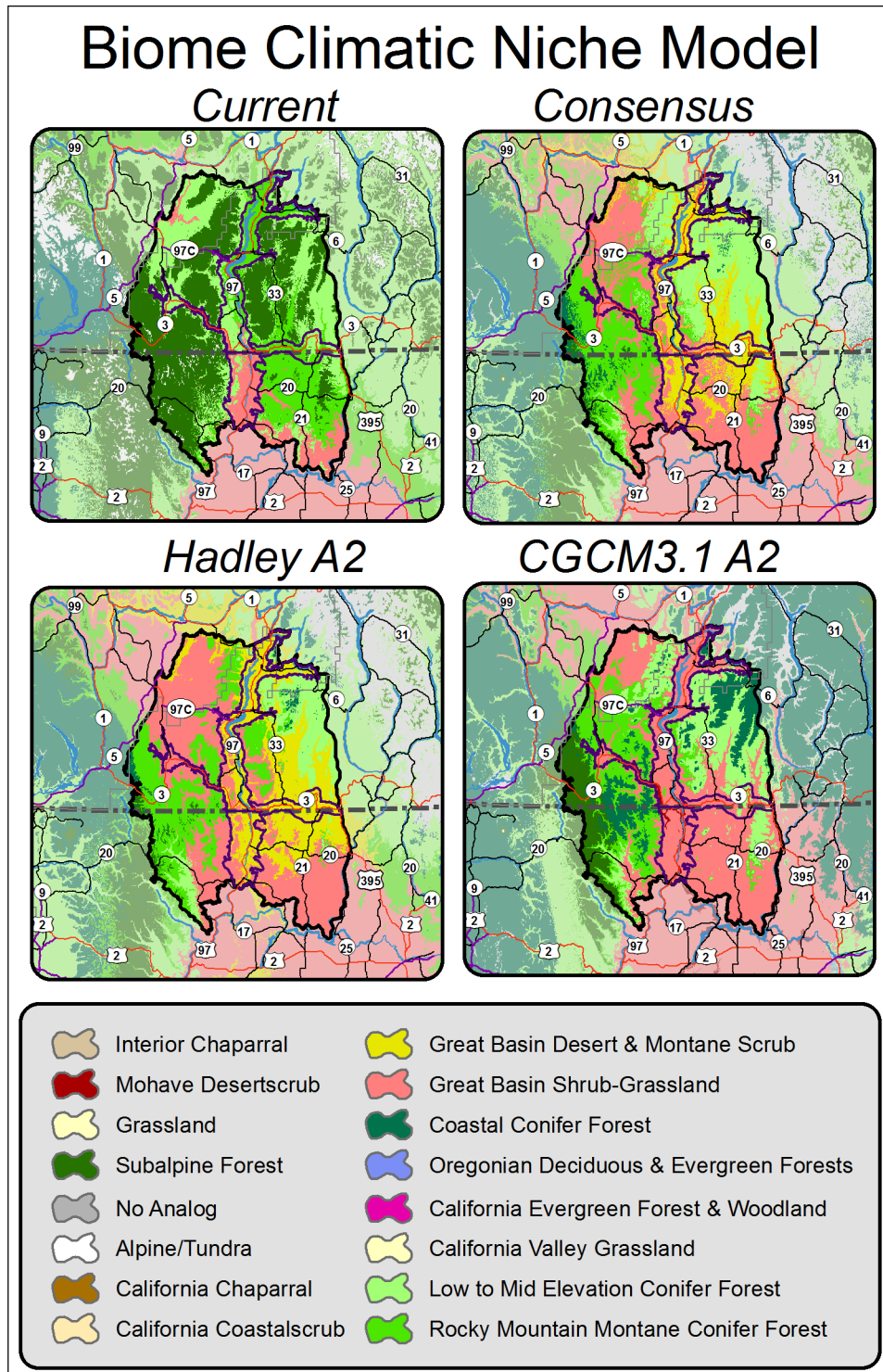
Appendix J.4a. Biome Climatic Niche Model

i) Extent: Okanagan Nation Territory



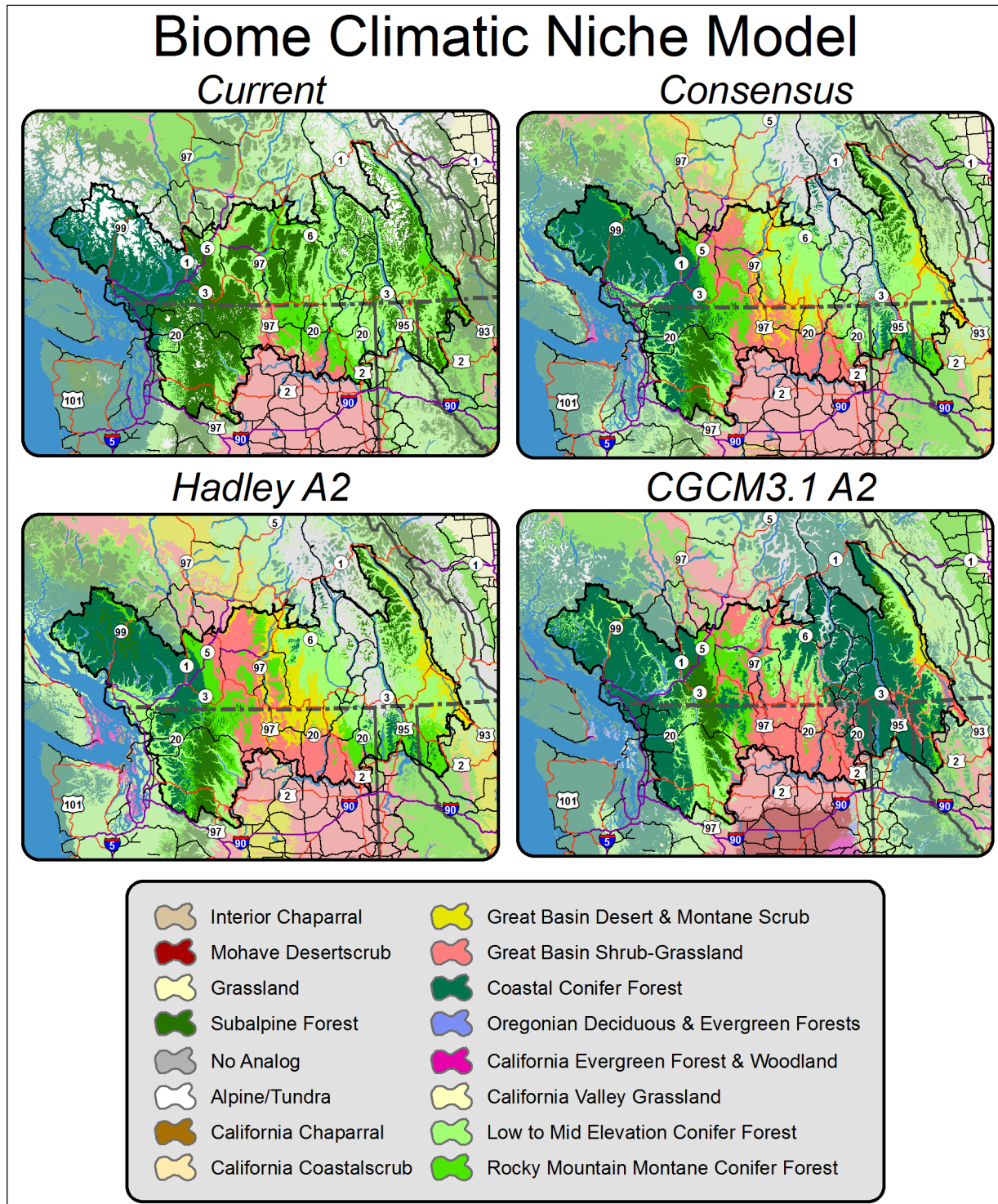
Appendix J.4a. Biome Climatic Niche Model

ii) Extent: Okanagan-Kettle Region



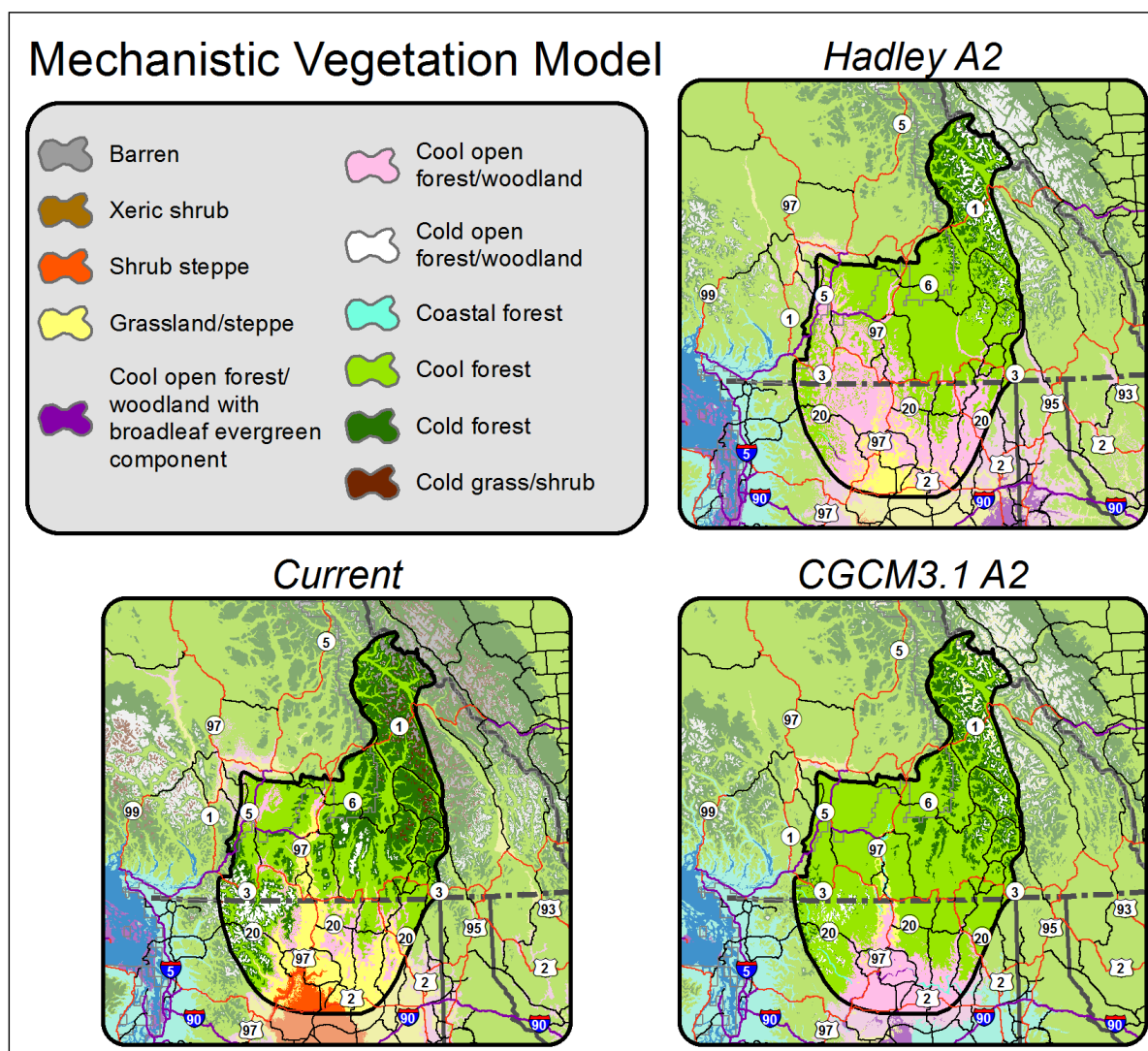
Appendix J.4a. Biome Climatic Niche Model

iii) Extent: Washington-British Columbia Transboundary Region



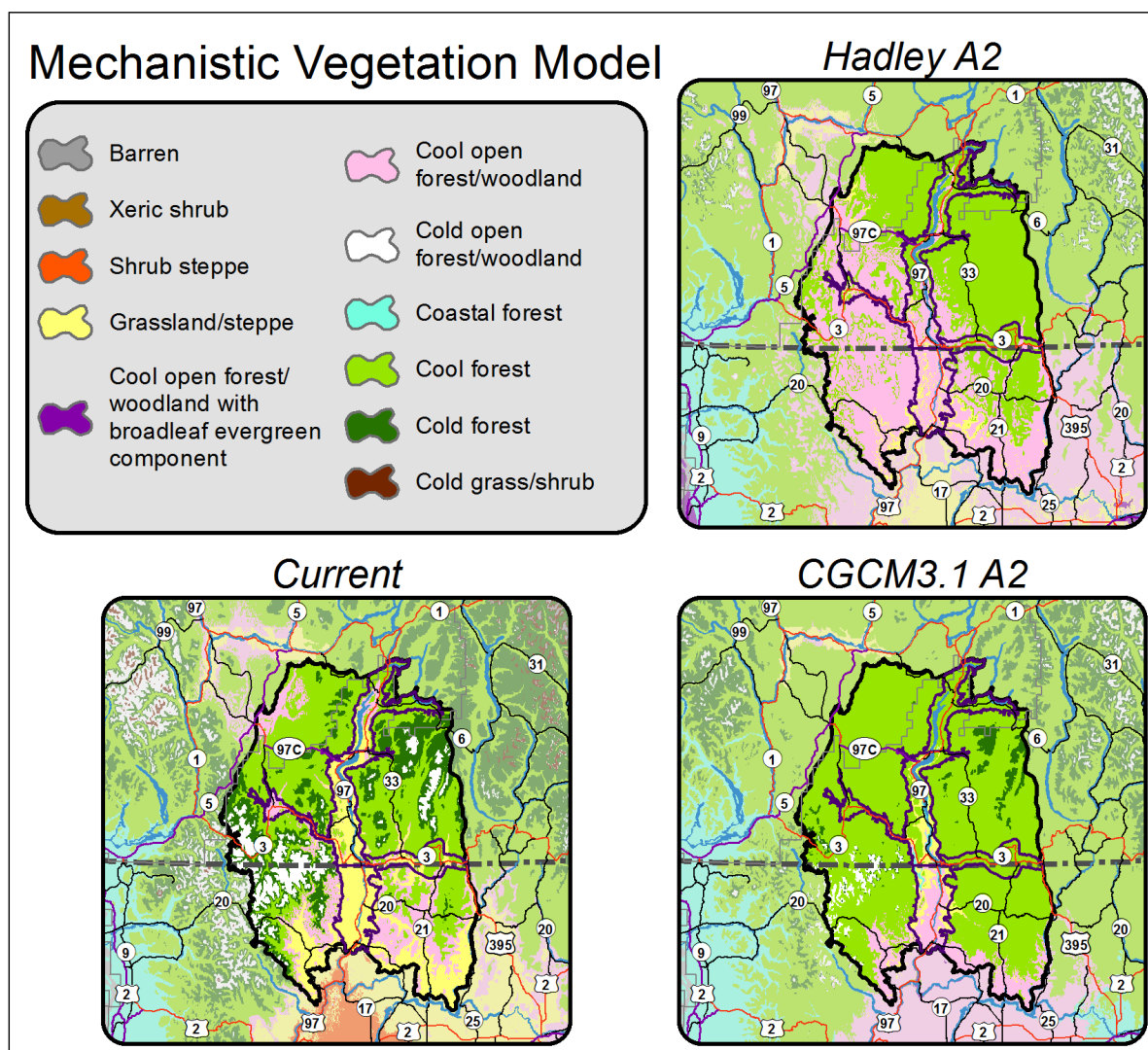
Appendix J.4b. Mechanistic Vegetation Model

i) Extent: Okanogan Nation Territory



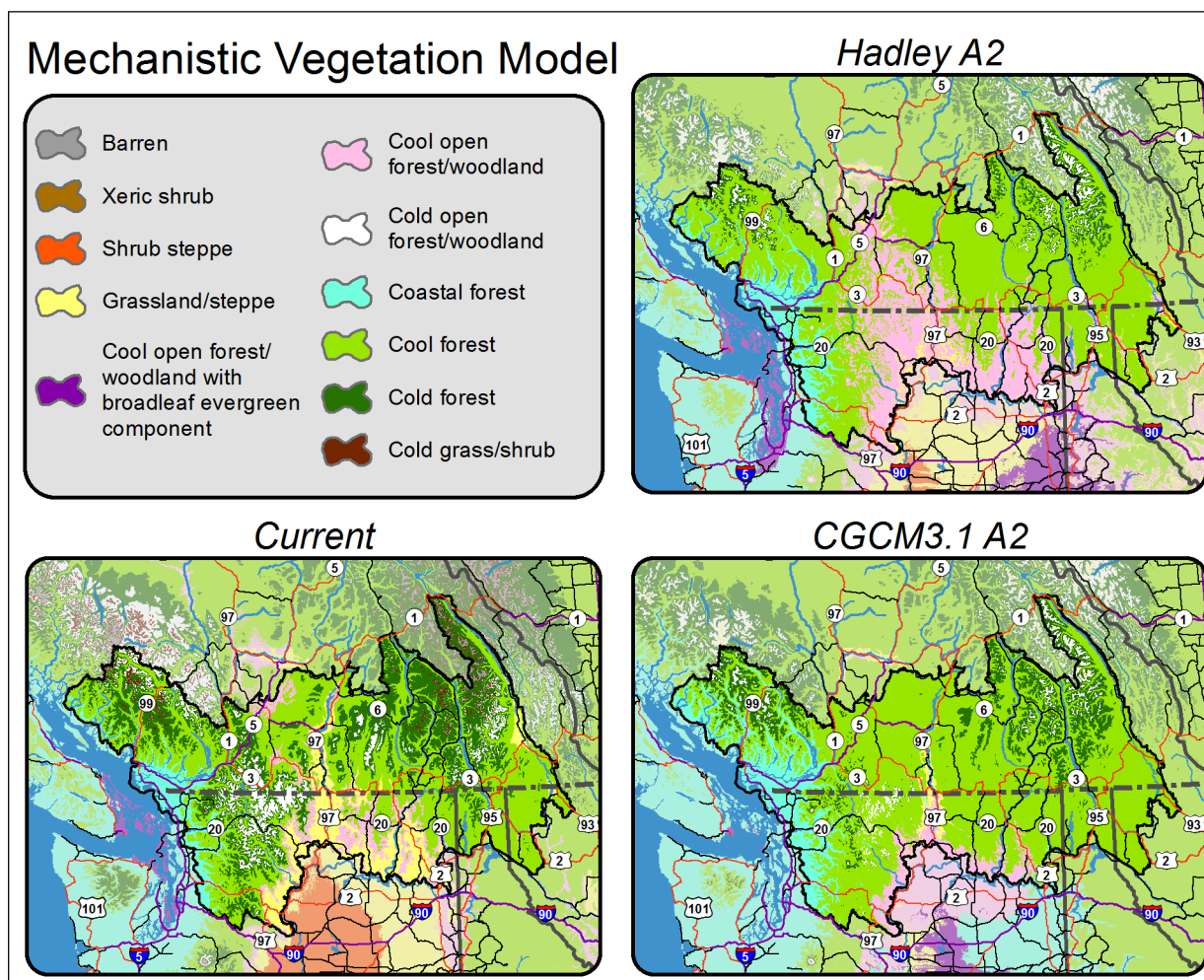
Appendix J.4b. Mechanistic Vegetation Model

ii) Extent: Okanagan-Kettle Region



Appendix J.4b. Mechanistic Vegetation Model

iii) Extent: Washington-British Columbia Transboundary Region



Appendix J.5. Projected Changes in Relevant Climate Variables

The following projections of future climate were identified by project partners as being most relevant to understanding and addressing climate impacts on tiger salamander connectivity.^{xv} Future climate projections were gathered from two sources, except where otherwise noted: 1) the Integrated Scenarios of the Pacific Northwest Environment,⁸ which is limited to the extent of the Columbia Basin; and the Pacific Climate Impacts Consortium's Regional Analysis Tool,⁹ which spans the full transboundary region. For many climatic variables, noticeable differences in the magnitude of future changes can be seen at the US-Canada border; this artifact results from differences on either side of the border in the number of weather stations, the way temperature and precipitation were measured, and differences in the approach used to process these data to produce gridded estimates of daily weather variations.

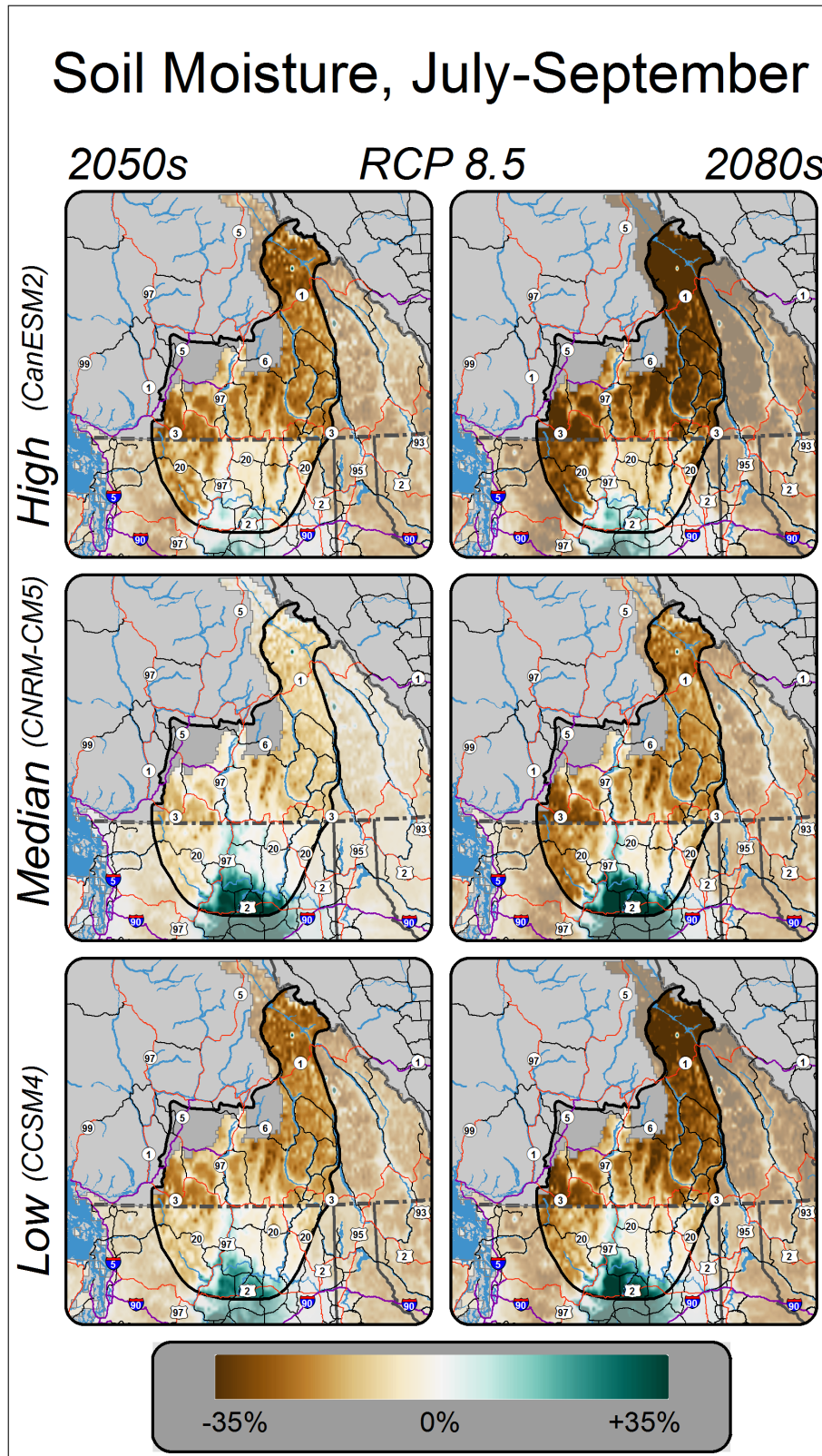
- a. **Soil Moisture, July-September.** This map shows the projected change, in percent, in summer soil moisture. Projected changes in soil moisture are depicted by the brown to green shading.
- b. **Evapotranspiration, March-May.** This map shows the percent change in evapotranspiration between March and May. Projected changes in spring evapotranspiration are depicted by the yellow to red shading.
- c. **Evapotranspiration, July-September.** This map shows the percent change in evapotranspiration between July and September. Projected changes in summer evapotranspiration are depicted by the teal to brown shading.
- d. **Total Spring Precipitation, March-May.** This map shows the projected change, in percent, in total spring (March-May) precipitation. Projected changes in total spring precipitation are depicted by the yellow to green shading.
- e. **Total Summer Precipitation, June-August.** This map shows the projected change, in percent, in total summer (June-August) precipitation. Projected changes in total summer precipitation are depicted by the teal to brown shading.
- f. **Total Spring Runoff.** This map shows projected change, in percent, in spring (March-May) runoff. This includes any overland water flows in addition to subsurface runoff in shallow groundwater. Projected changes in spring runoff are depicted by the yellow to green shading.
- g. **Total Summer Runoff.** This map shows projected change, in percent, in summer (July-September) runoff. This includes any overland water flows in addition to subsurface runoff in shallow groundwater. Projected changes in spring runoff are depicted by the teal to brown shading.
- h. **Increase in Average Annual Daytime Temperature.** This map shows the projected change in average annual daytime temperature in degrees Celsius. Projected temperature increases are depicted by the yellow to orange shading.

^{xv} All projections are evaluated for the 2050s (2040-2069) and the 2080s (2070-2099), based on 3 global climate models (a high (CanESM2), median (CNRM-CM5), and low (CCSM4)), under a high greenhouse gas scenario (RCP 8.5).

- i. **Spring (April 1st) Snowpack.** This map shows the percent change in snow water equivalent (SWE) on April 1st. April 1st is the approximate current timing of peak annual snowpack in Northwest mountains. SWE is a measure of the total amount of water contained in the snowpack. Projected decreases in SWE are depicted by the yellow to red shading.

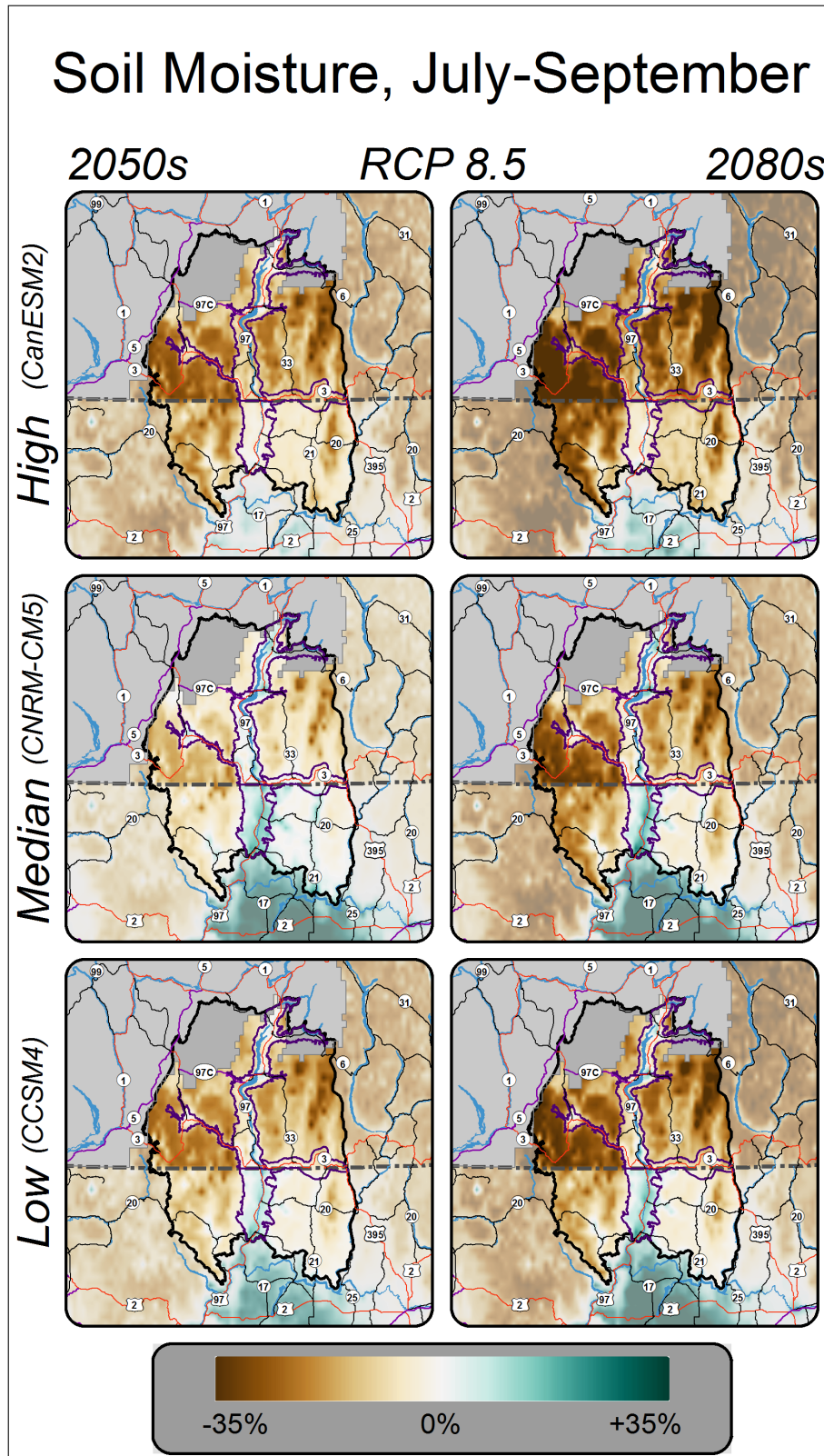
Appendix J.5a. Summer Soil Moisture, July-September

i) Extent: Okanagan Nation Territory



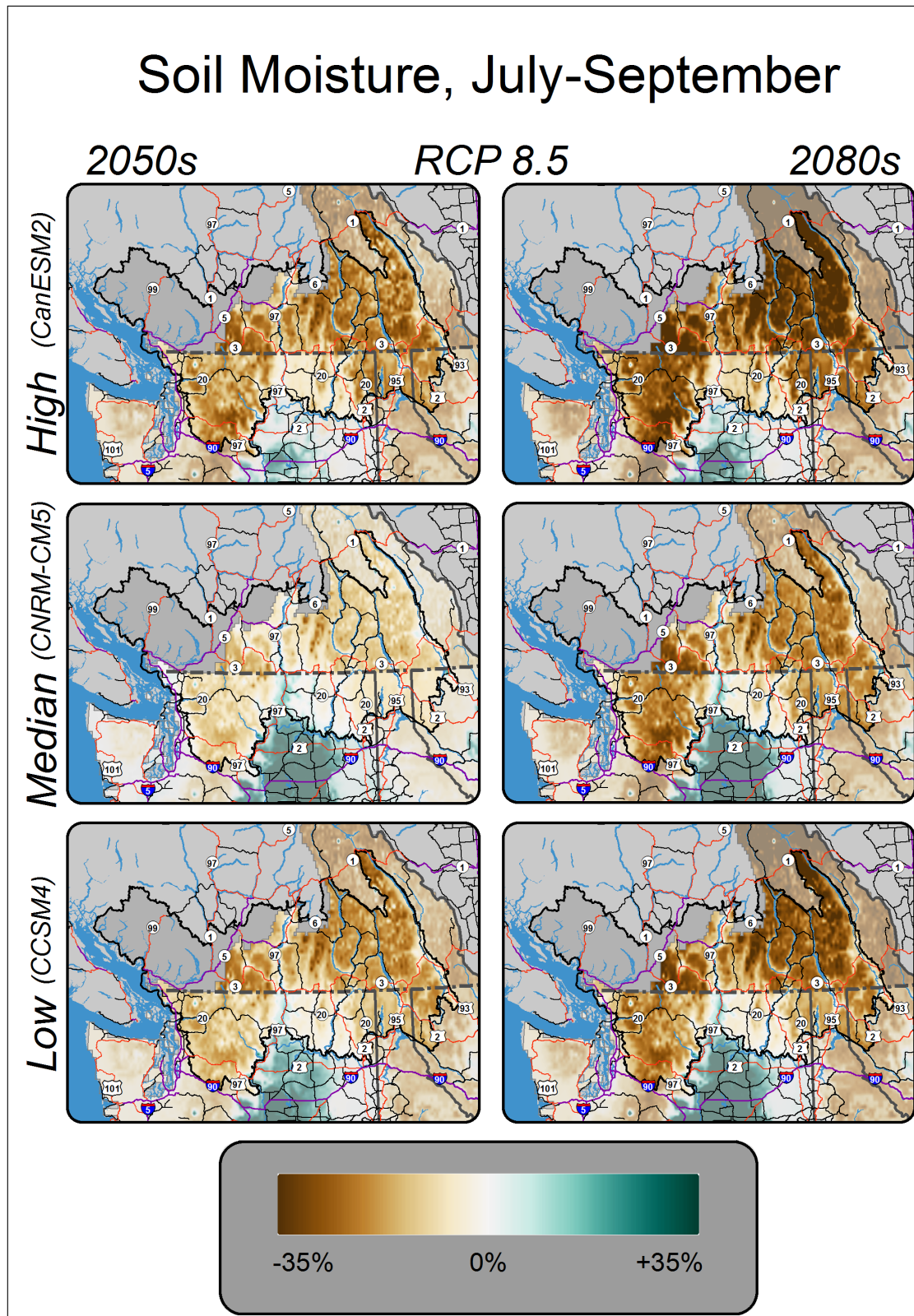
Appendix J.5a. Summer Soil Moisture, July-September

ii) Extent: Okanagan-Kettle Region



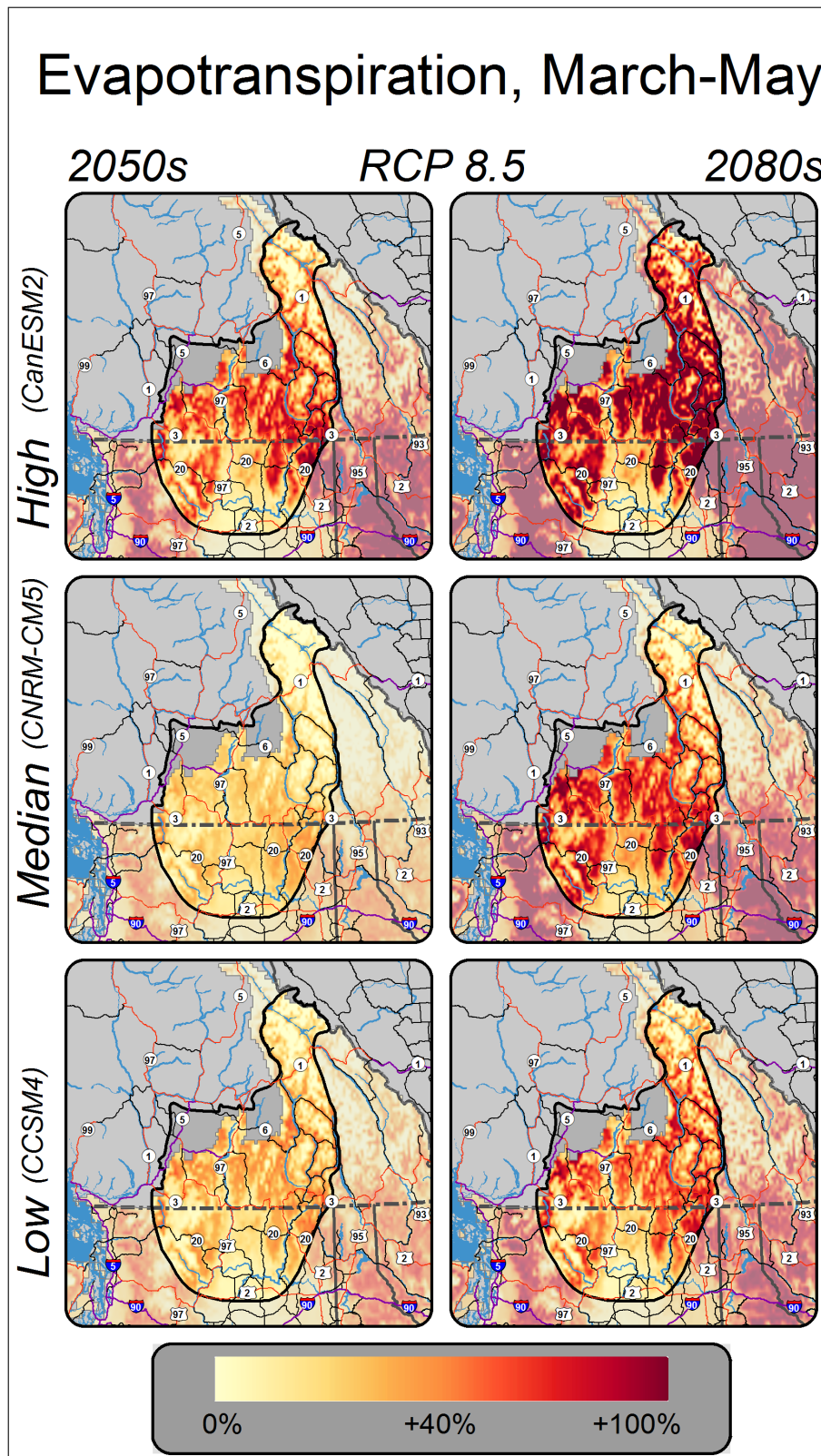
Appendix J.5a. Summer Soil Moisture, July-September

iii) Extent: Washington-British Columbia Transboundary Region



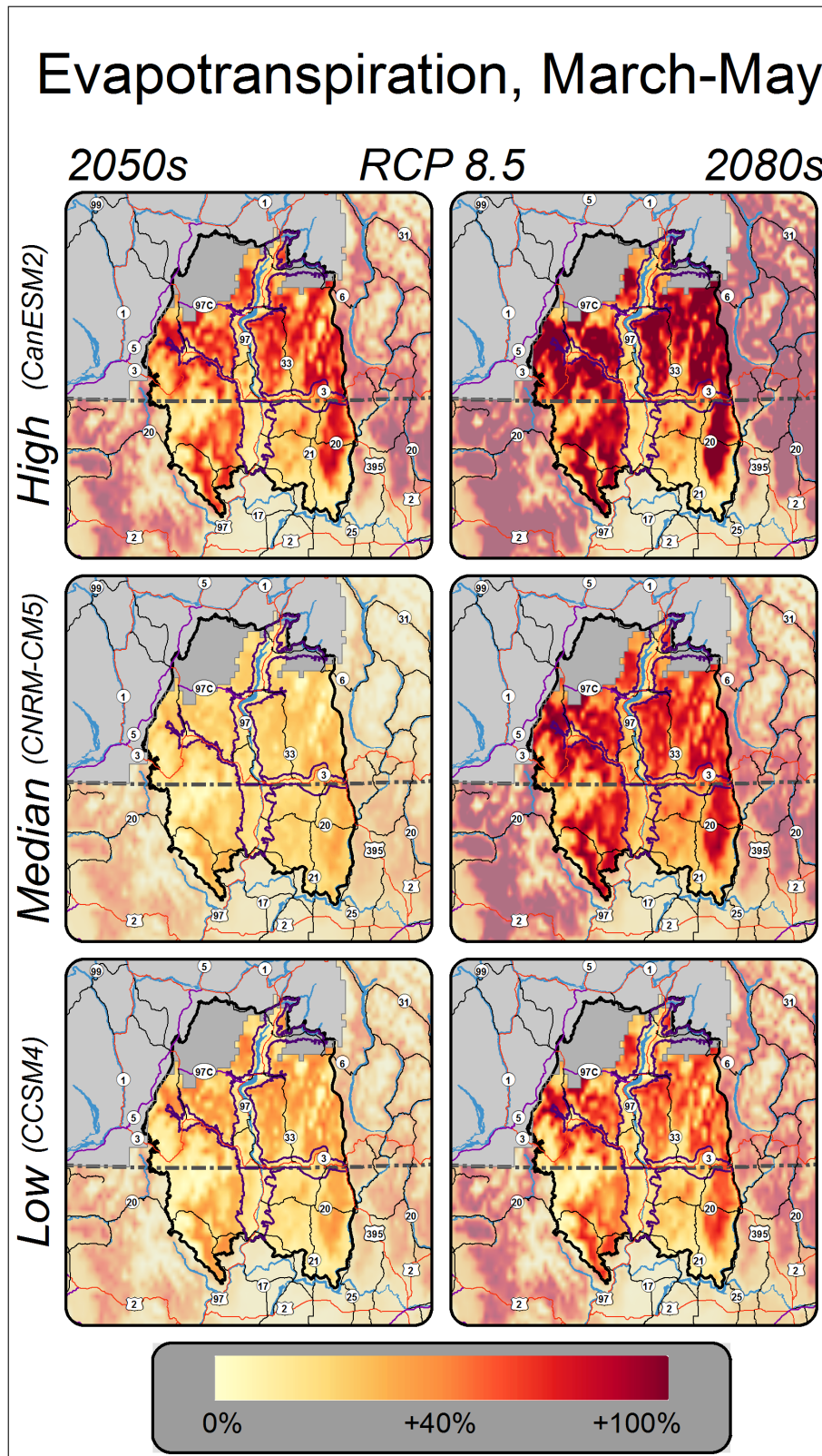
Appendix J.5b. Evapotranspiration, March-May

i) Extent: Okanagan Nation Territory



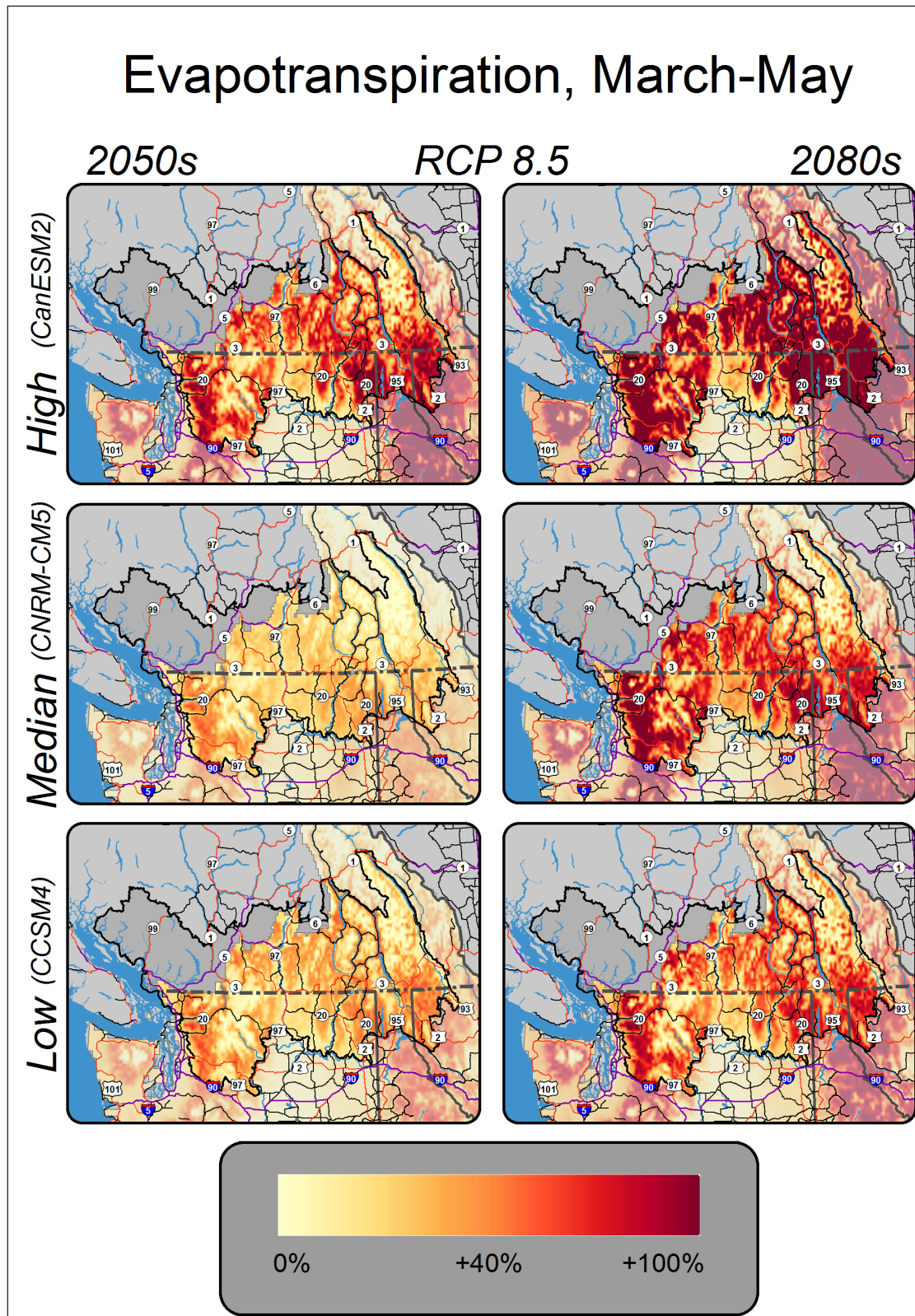
Appendix J.5b. Evapotranspiration, March-May

ii) Extent: Okanagan-Kettle Region



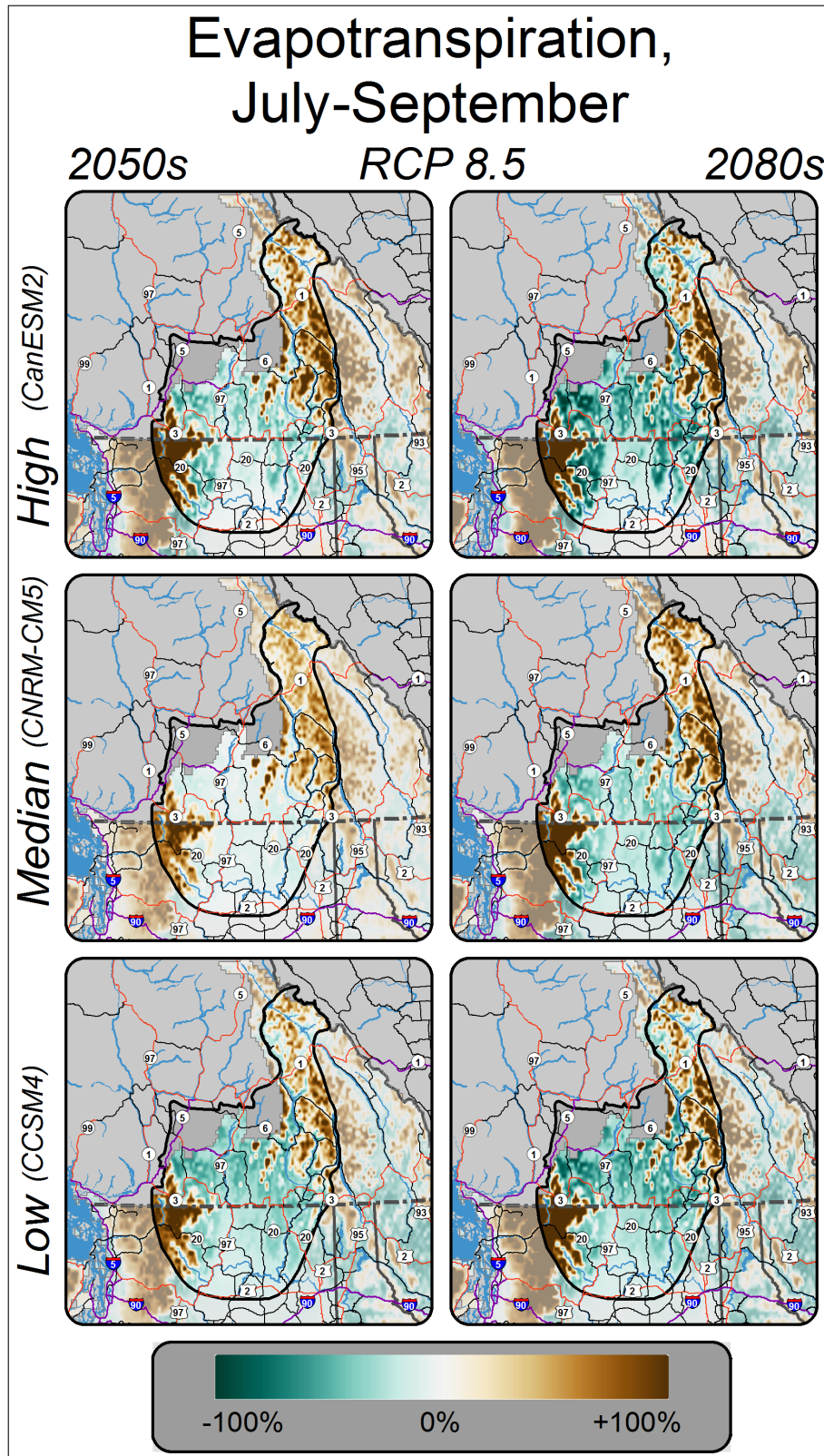
Appendix J.5b. Evapotranspiration, March-May

iii) Extent: Washington-British Columbia Transboundary Region



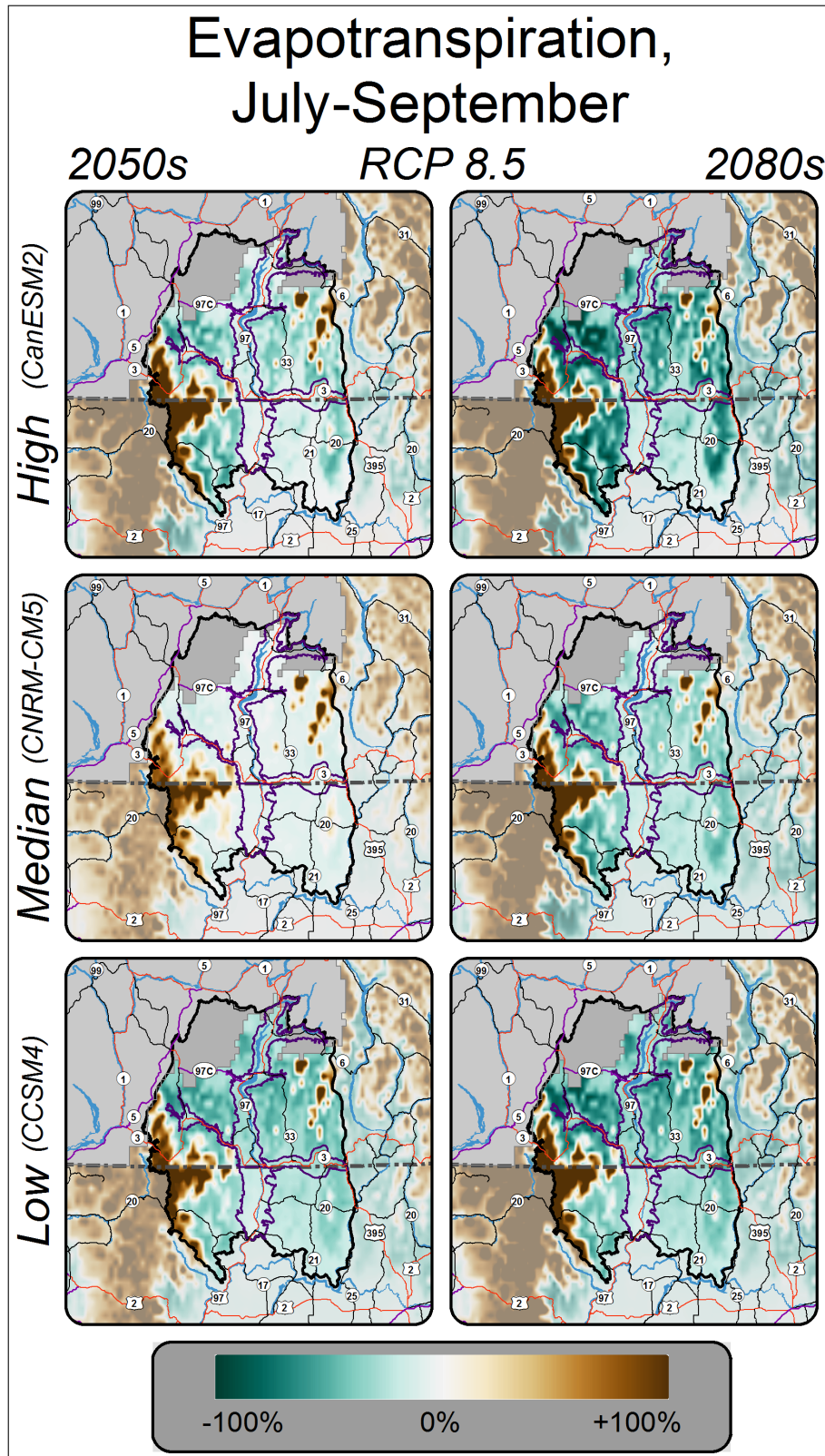
Appendix J.5c. Evapotranspiration, July-September

i) Extent: Okanagan Nation Territory



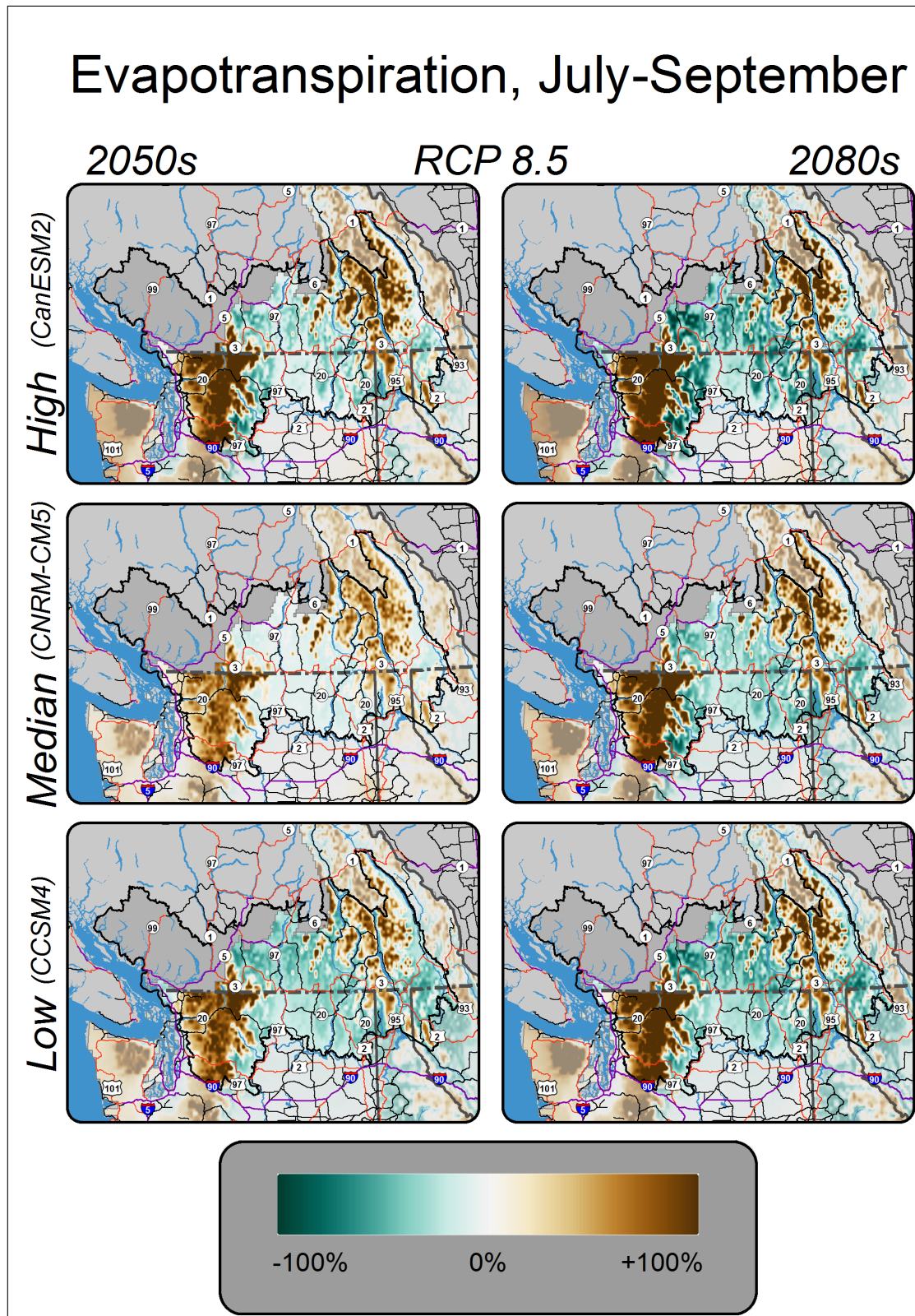
Appendix J.5c. Evapotranspiration, July-September

ii) Extent: Okanagan-Kettle Region



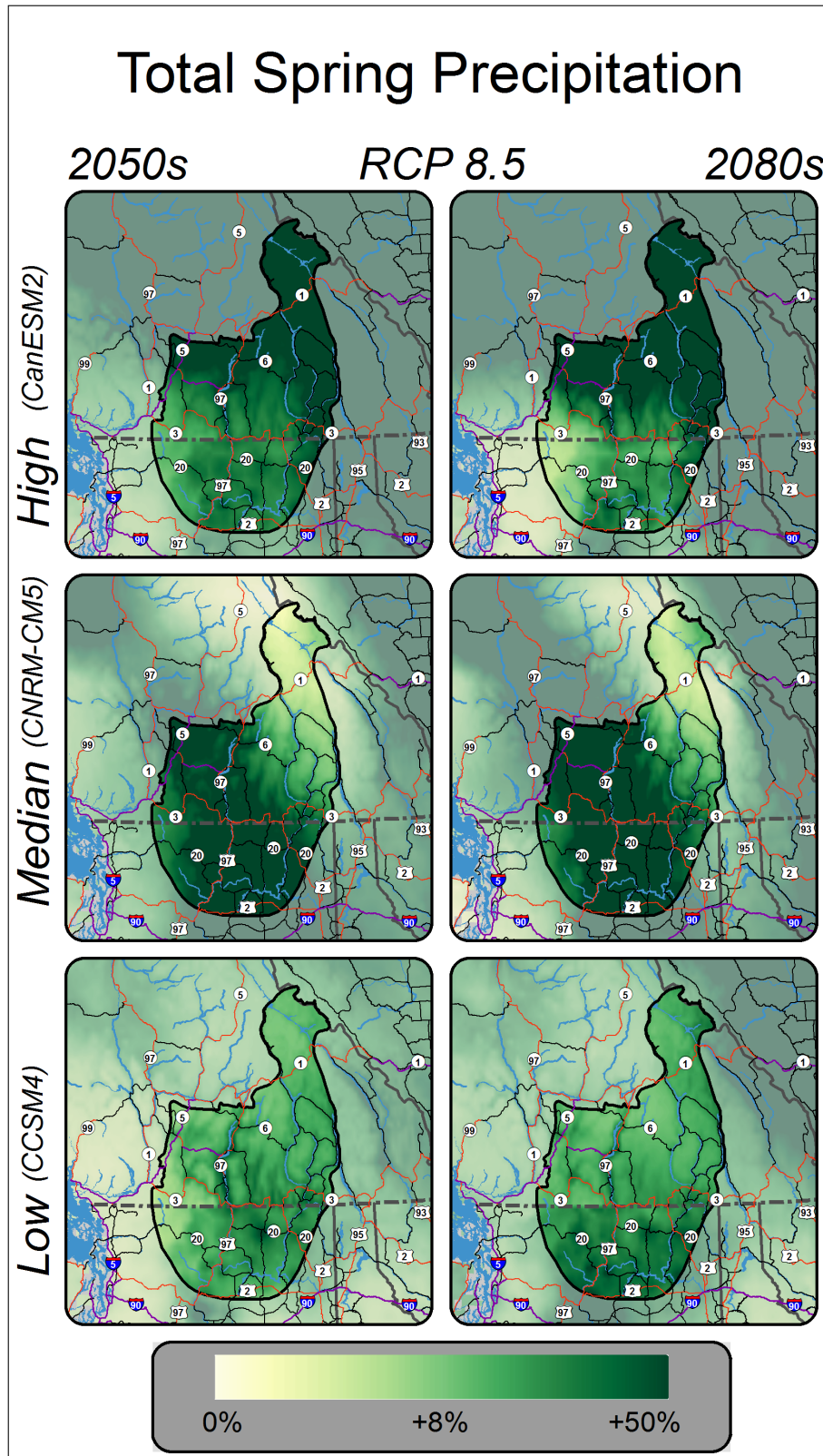
Appendix J.5c. Evapotranspiration, July-September

iii) Extent: Washington-British Columbia Transboundary Region



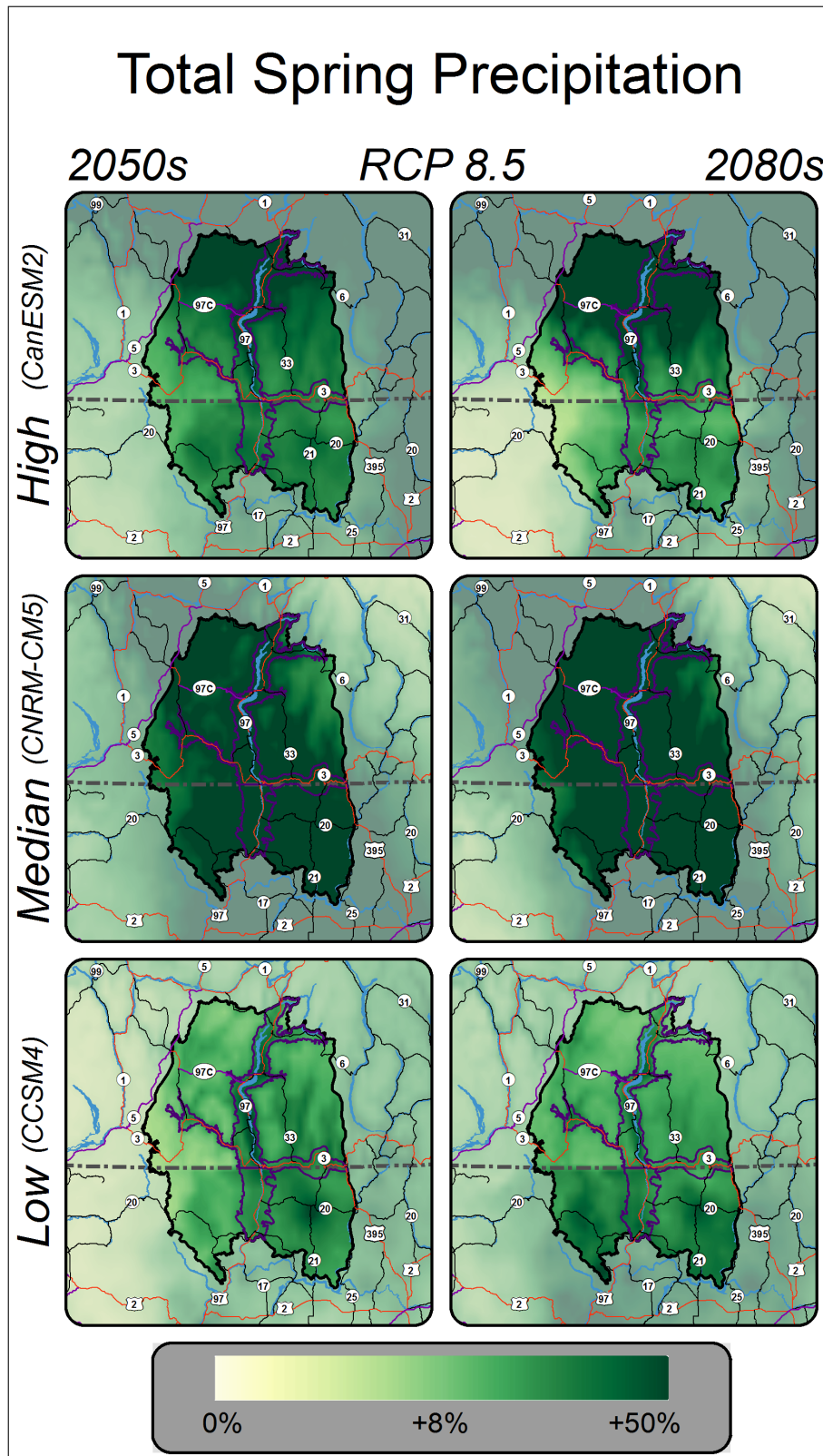
Appendix J.5d. Total Spring Precipitation, March-May

i) Extent: Okanagan Nation Territory



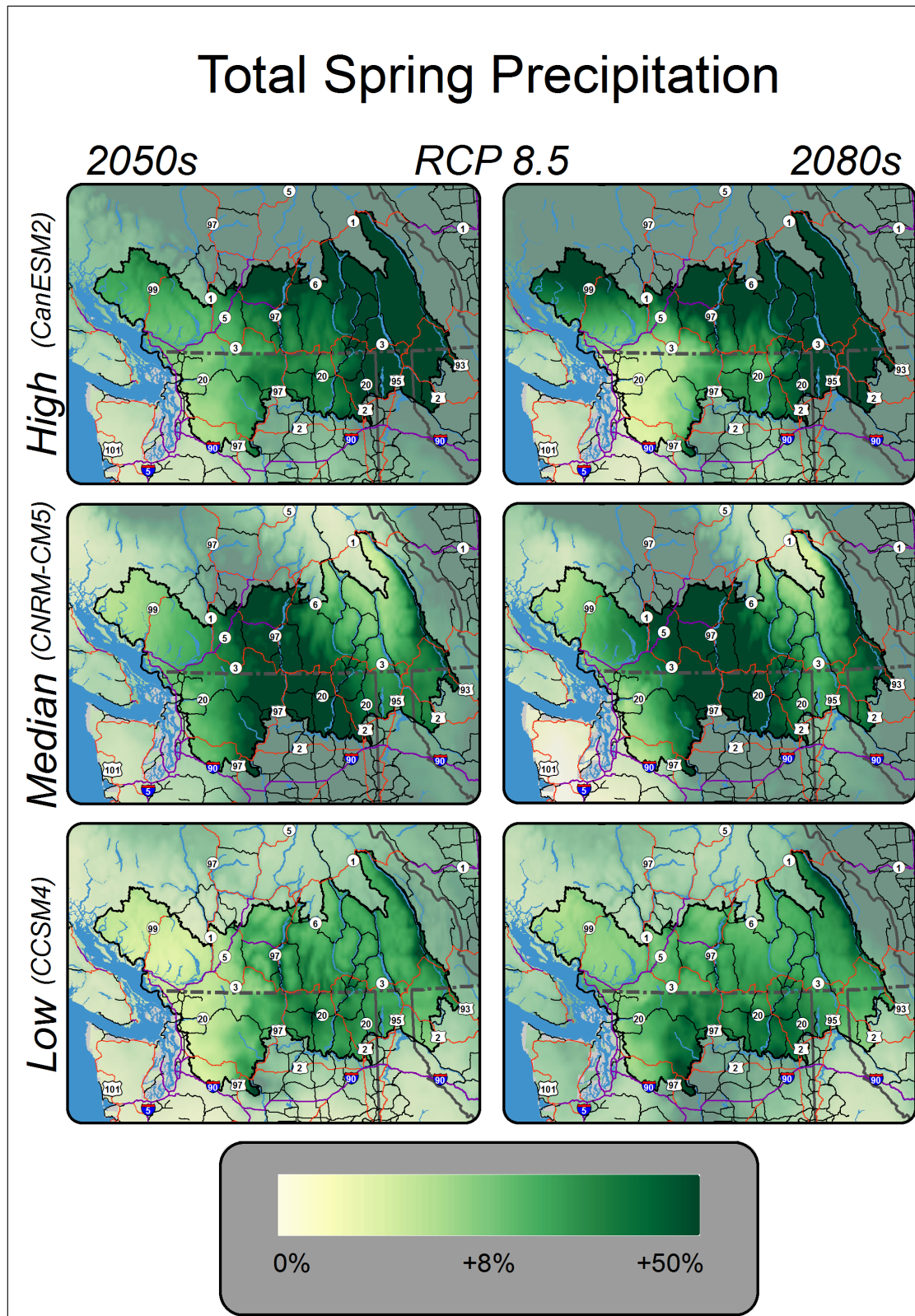
Appendix J.5d. Total Spring Precipitation, March-May

ii) Extent: Okanagan-Kettle Region



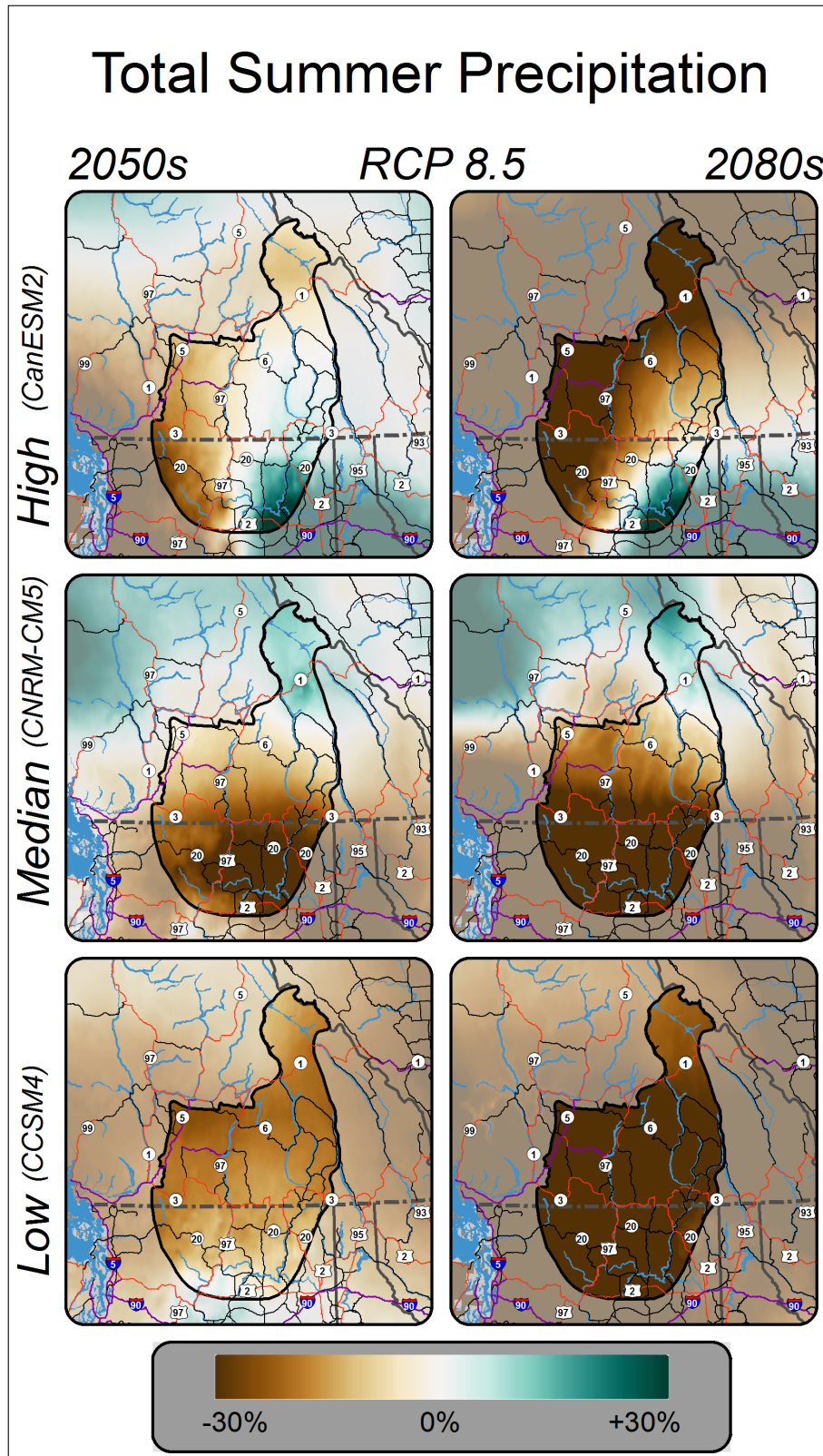
Appendix J.5d. Total Spring Precipitation, March-May

iii) Extent: Washington-British Columbia Transboundary Region



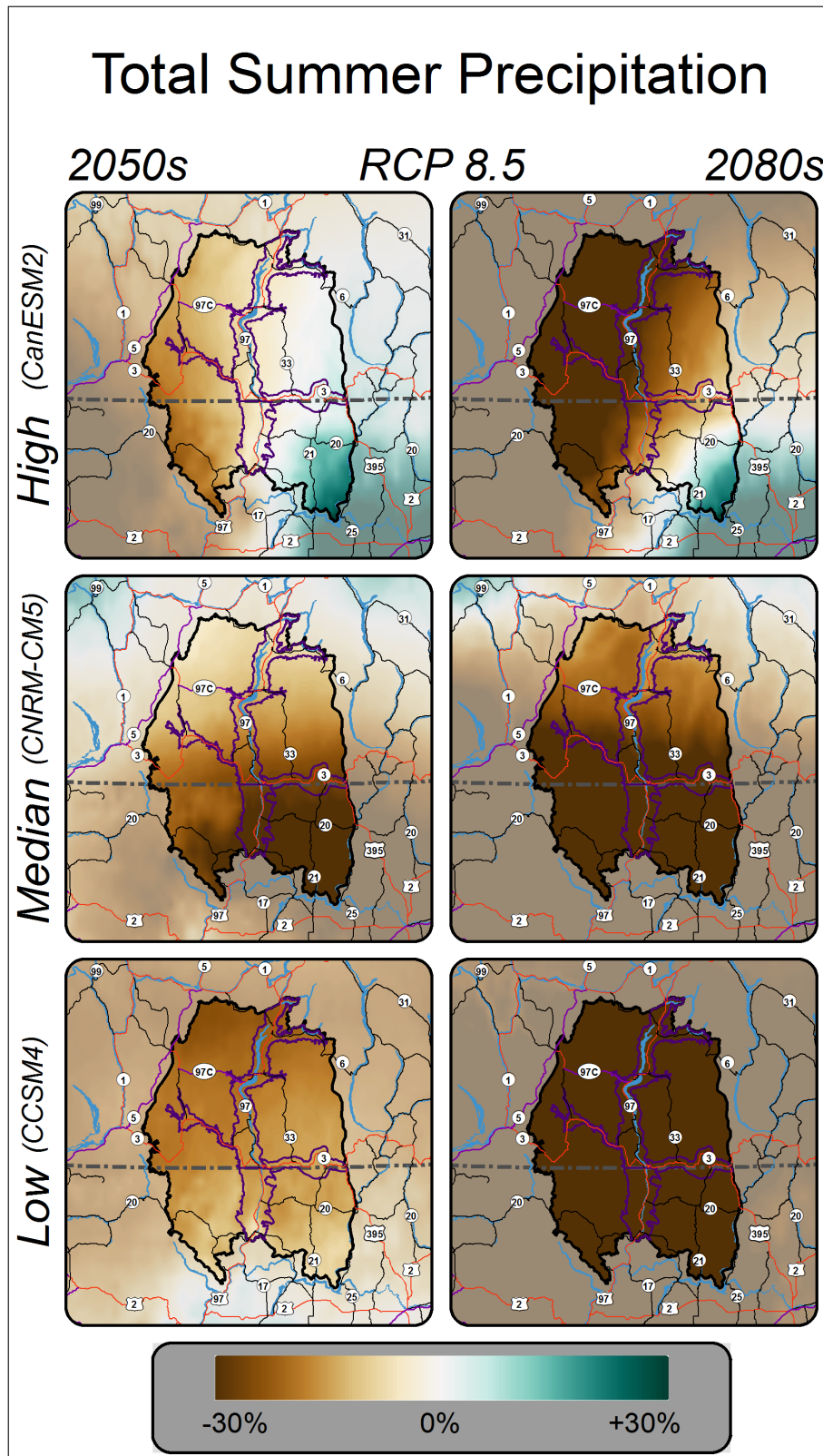
Appendix J.5e. Total Summer Precipitation, July-September

i) Extent: Okanagan Nation Territory



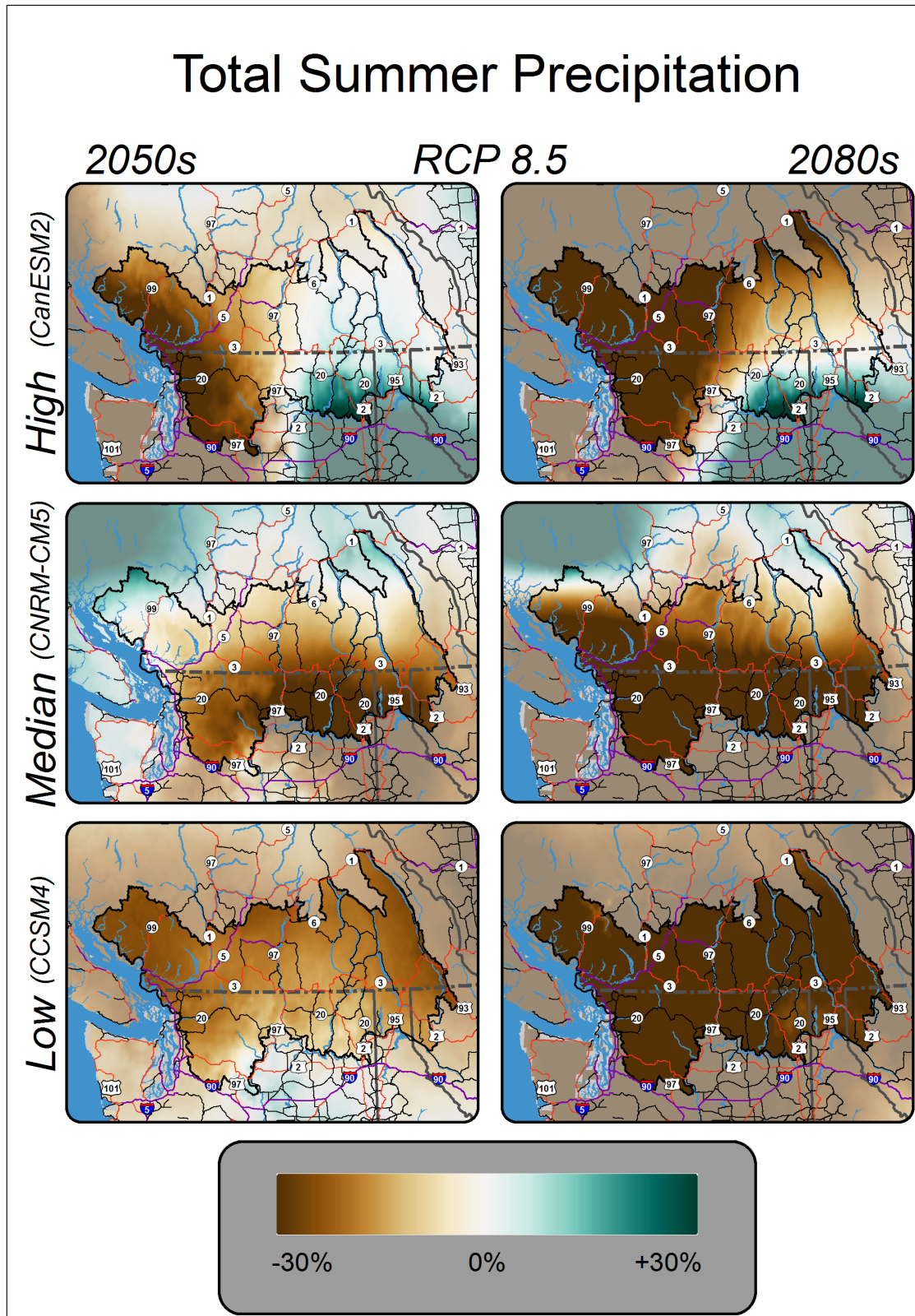
Appendix J.5e. Total Summer Precipitation, July-September

ii) Extent: Okanagan-Kettle Region



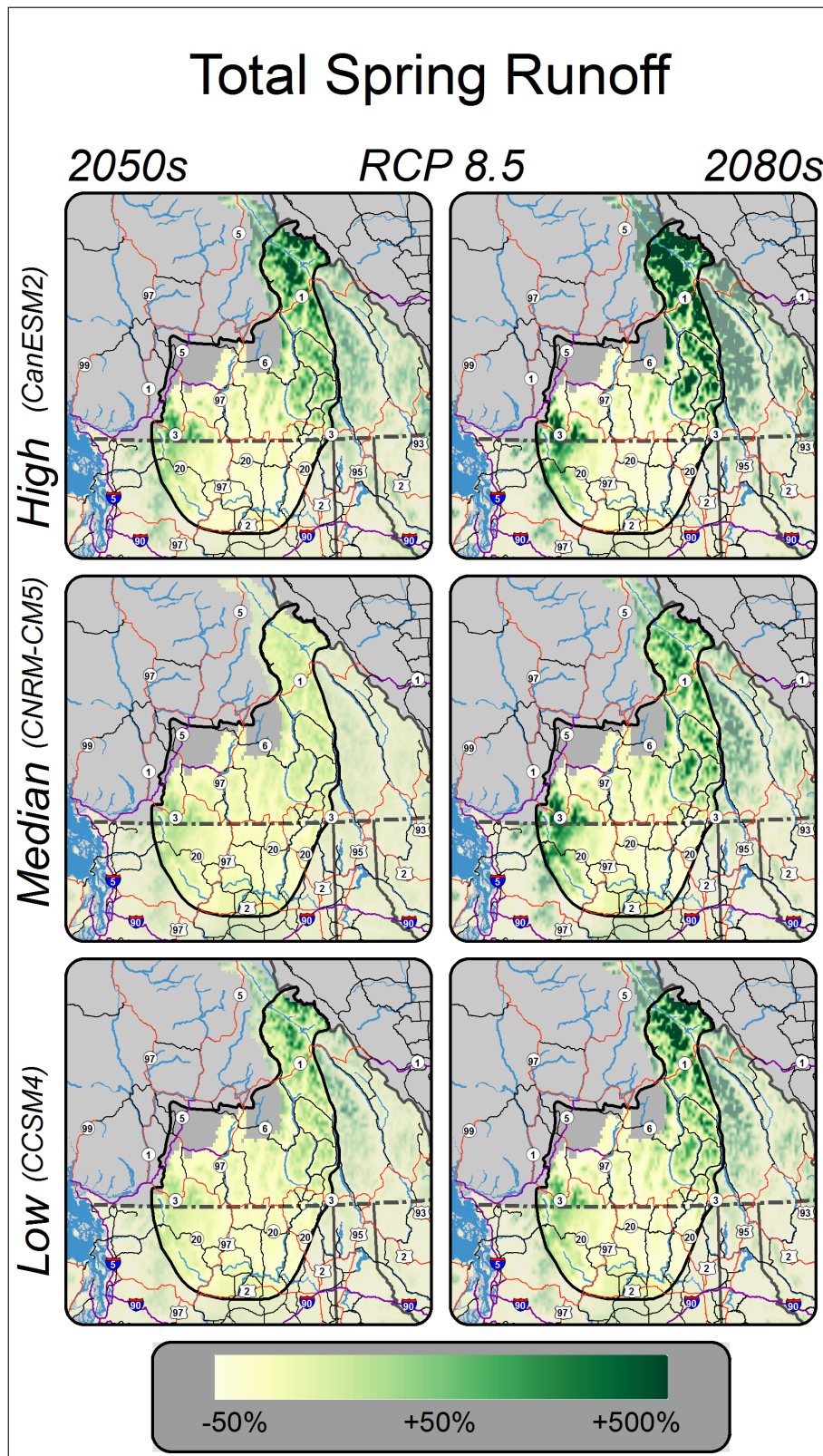
Appendix J.5e. Total Summer Precipitation, July-September

iii) Extent: Washington-British Columbia Transboundary Region



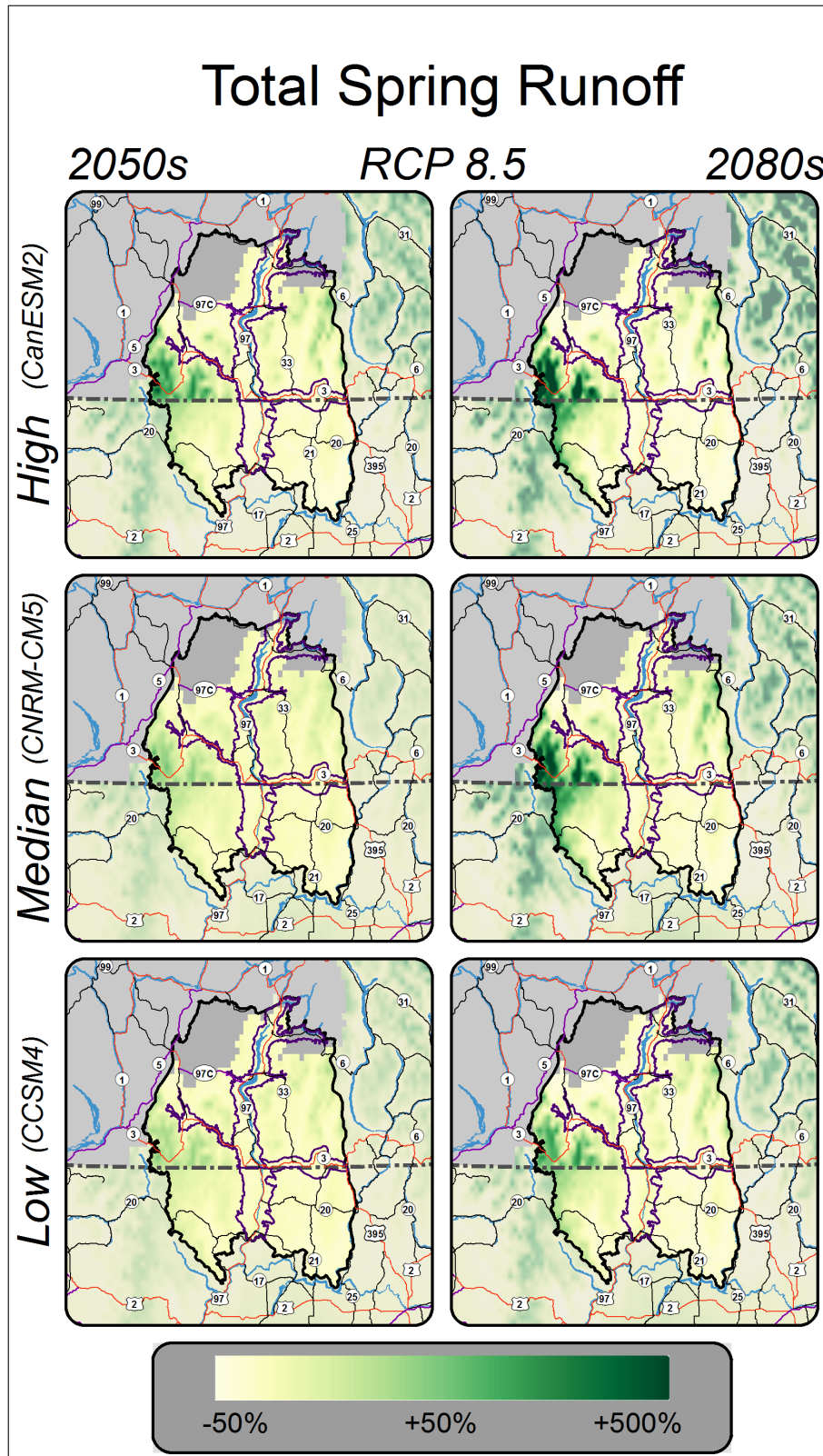
Appendix J.5f. Total Spring Runoff

i) Extent: Okanagan Nation Territory



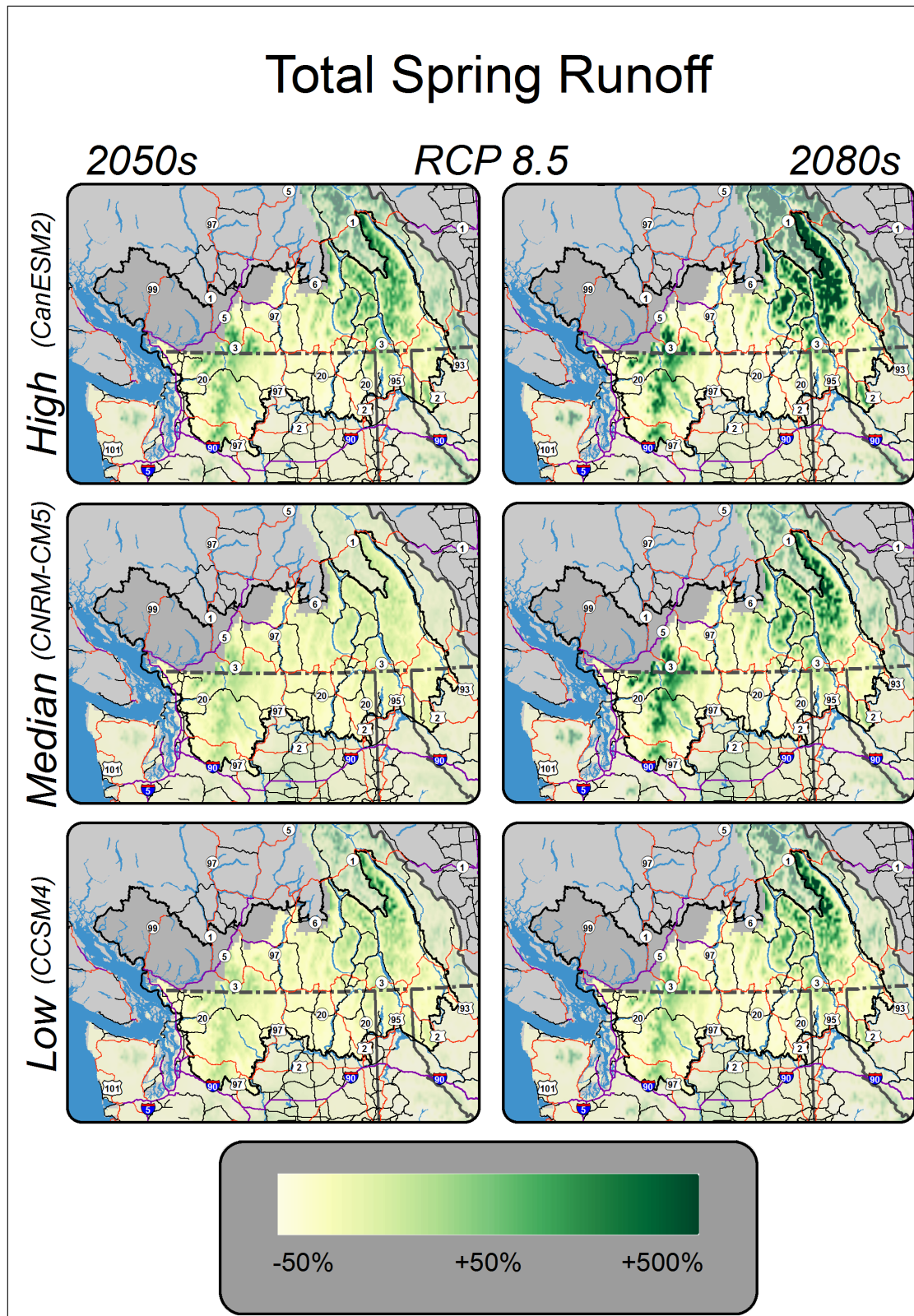
Appendix J.5f. Total Spring Runoff

ii) Extent: Okanagan-Kettle Region



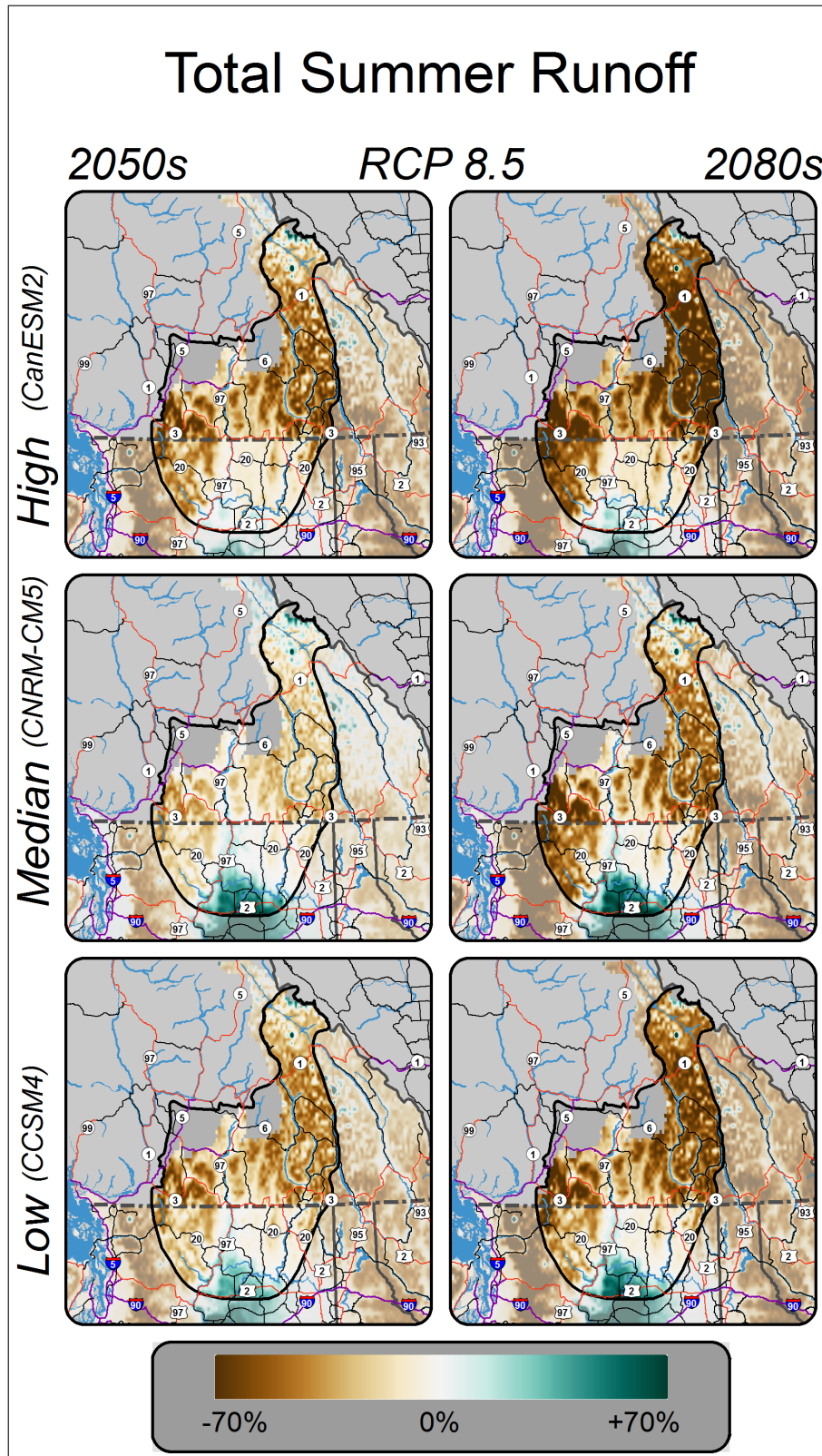
Appendix J.5f. Total Spring Runoff

iii) Extent: Washington-British Columbia Transboundary Region



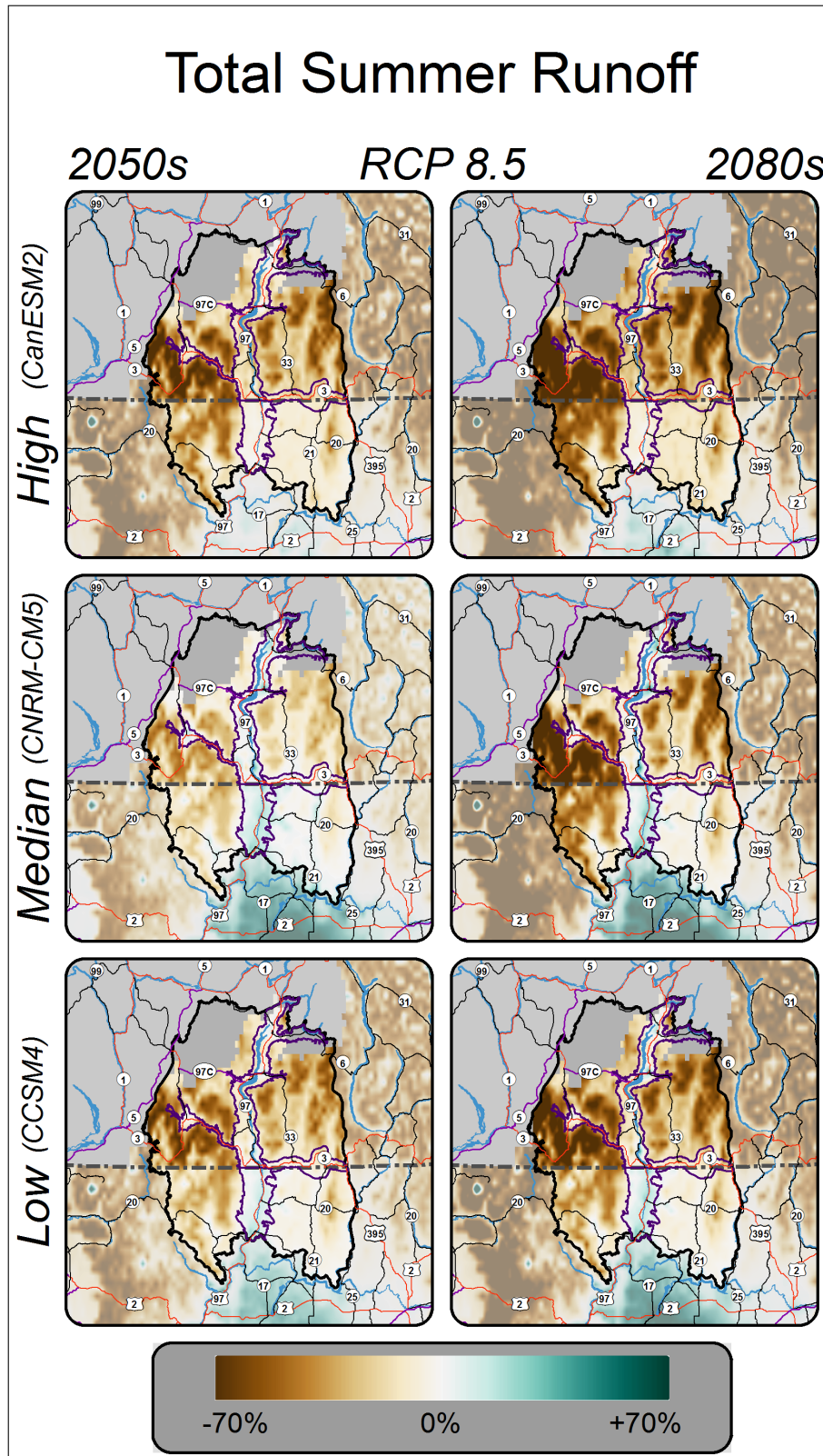
Appendix J.5g. Total Summer Runoff

i) Extent: Okanagan Nation Territory



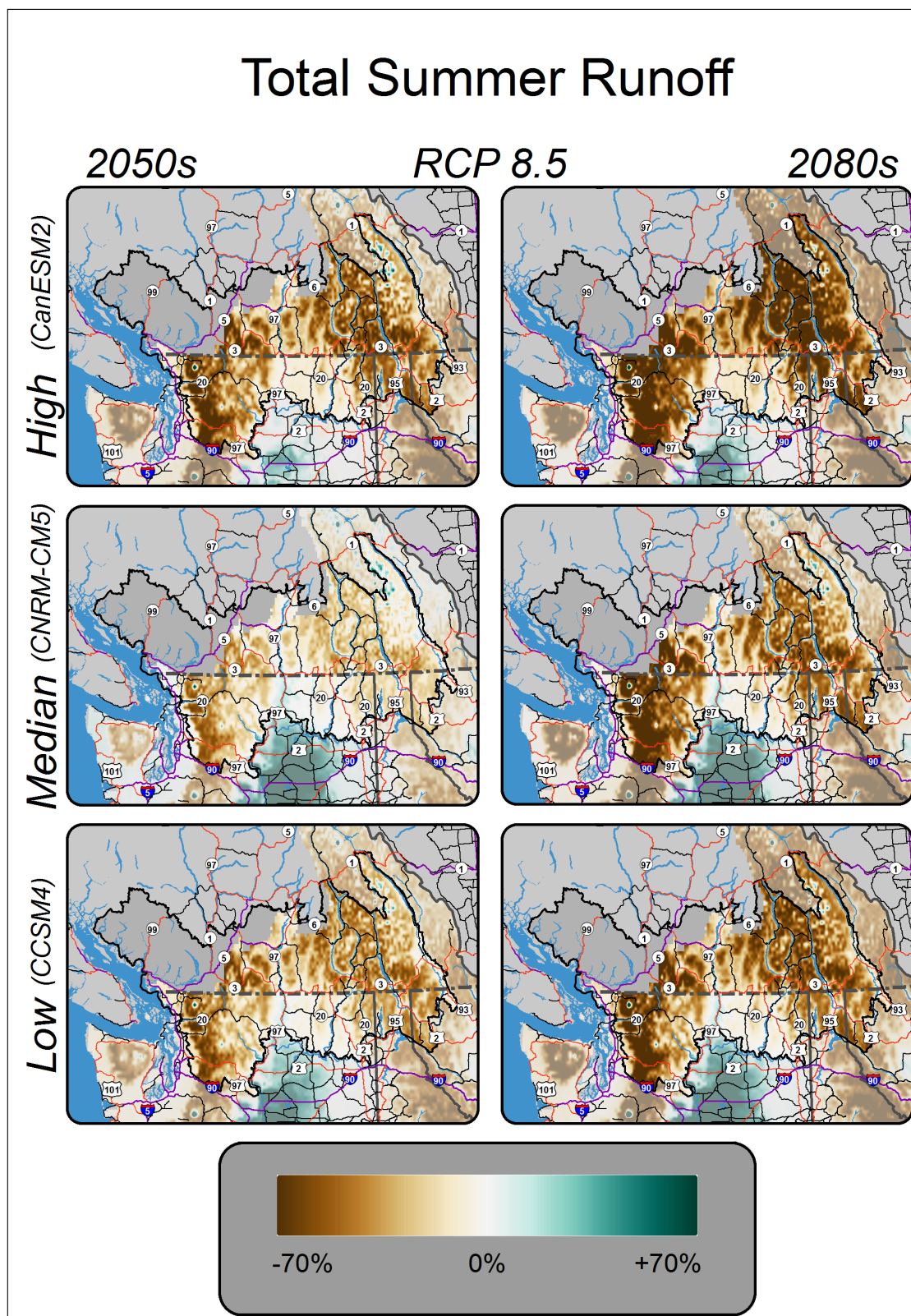
Appendix J.5g. Total Summer Runoff

ii) Extent: Okanagan-Kettle Region



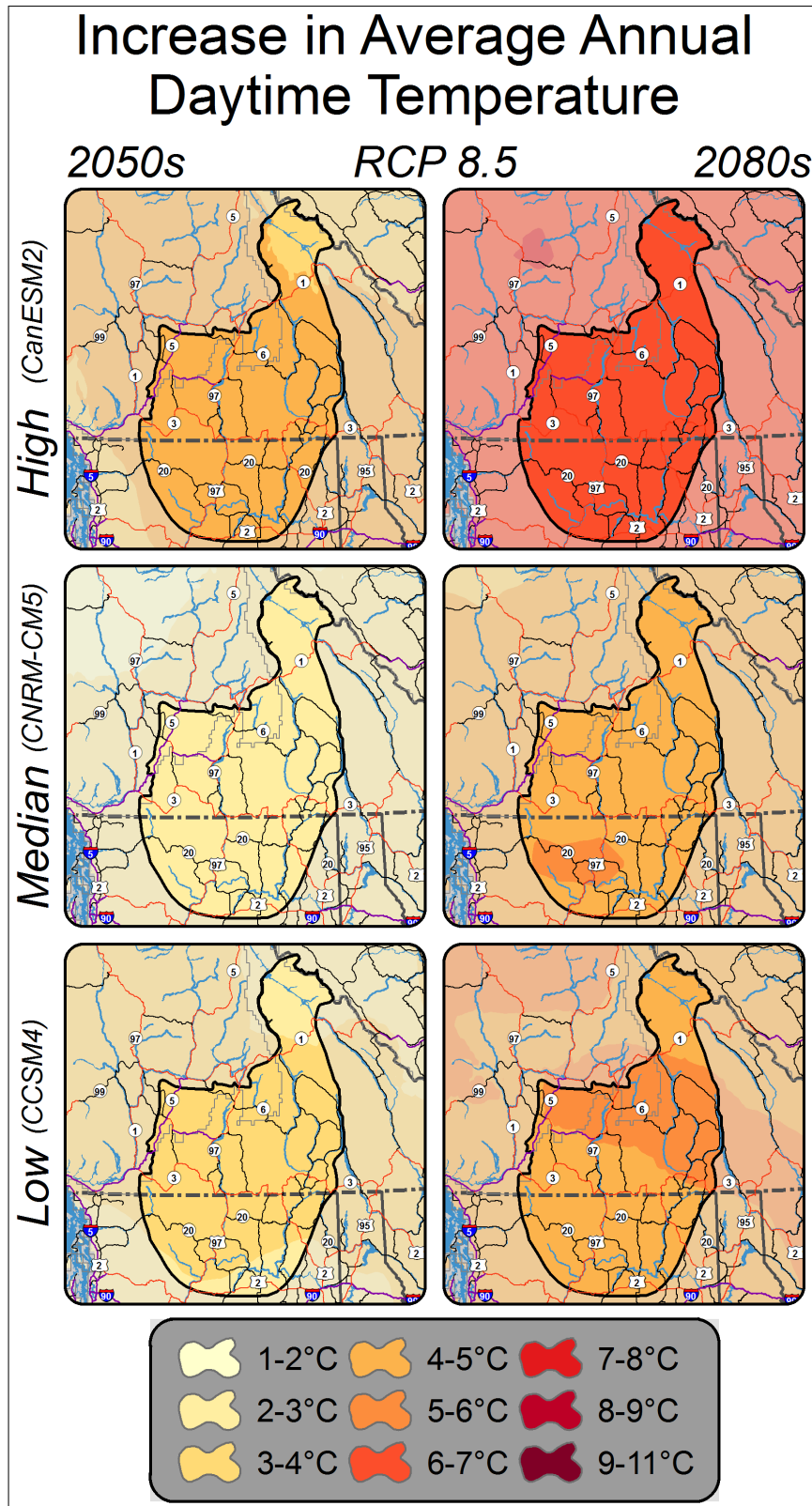
Appendix J.5g. Total Summer Runoff

iii) Extent: Washington-British Columbia Transboundary Region



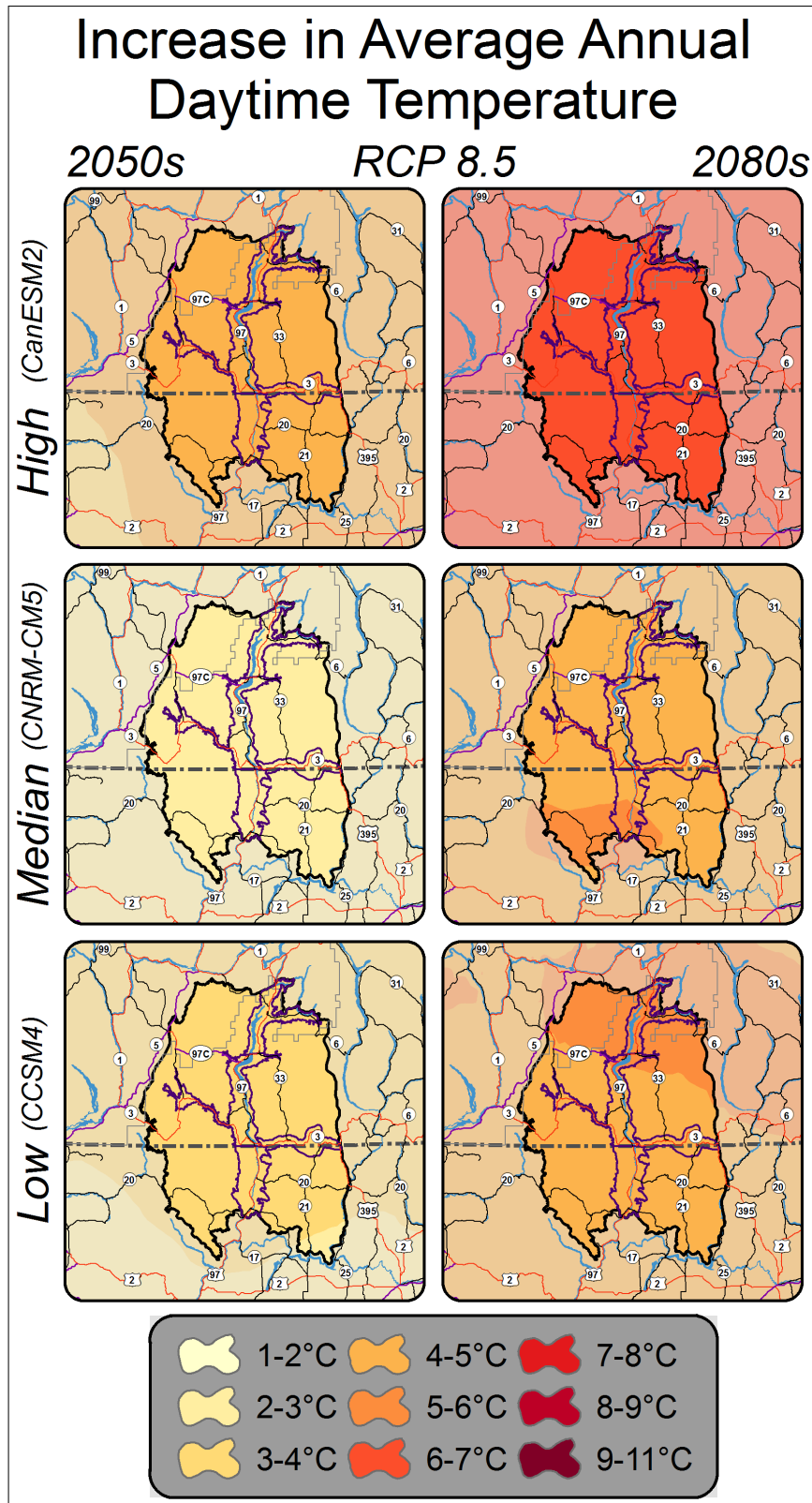
Appendix J.5h. Increase in Average Annual Daytime Temperature

i) Extent: Okanagan Nation Territory



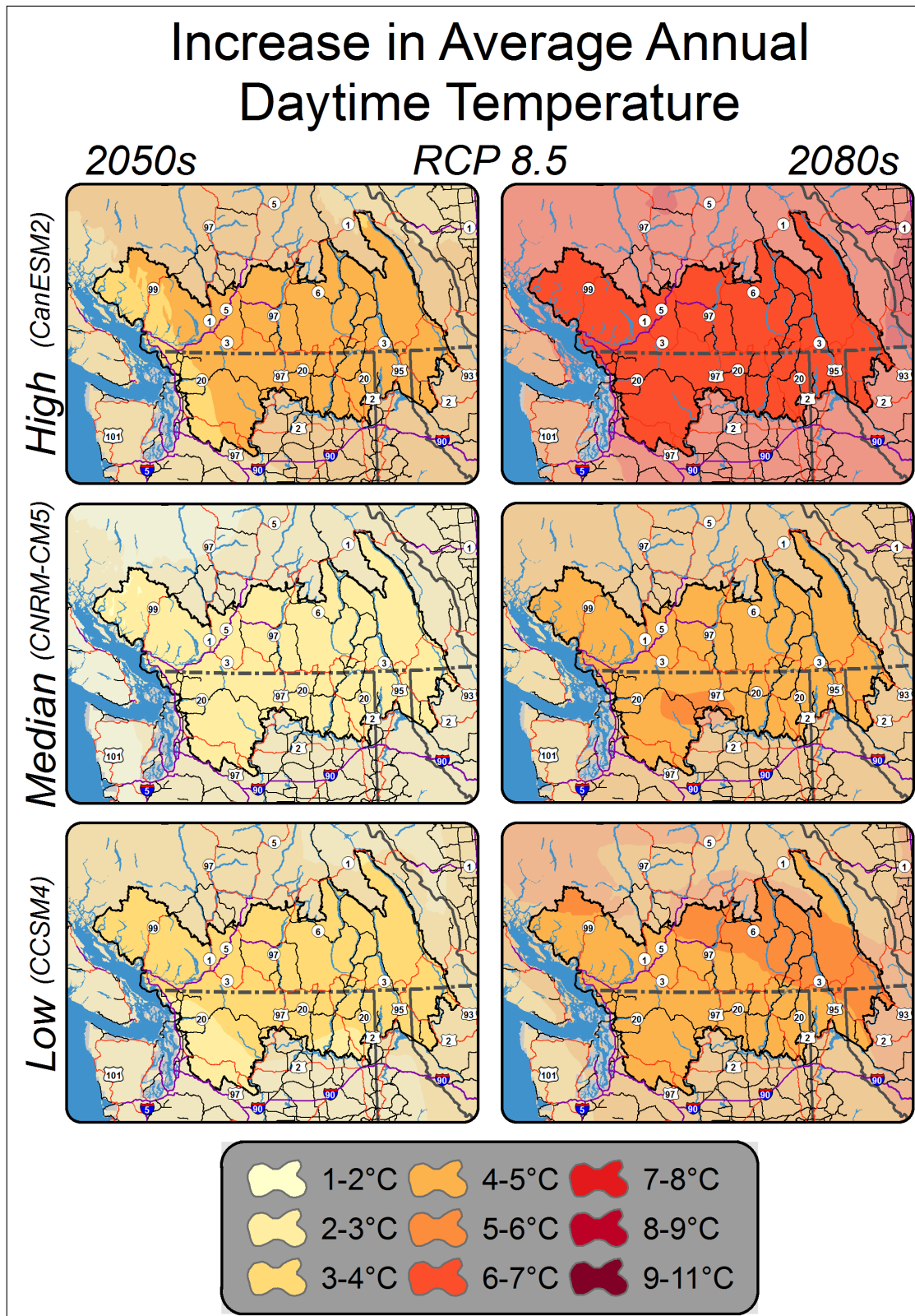
Appendix J.5h. Increase in Average Annual Daytime Temperature

ii) Extent: Okanagan-Kettle Region



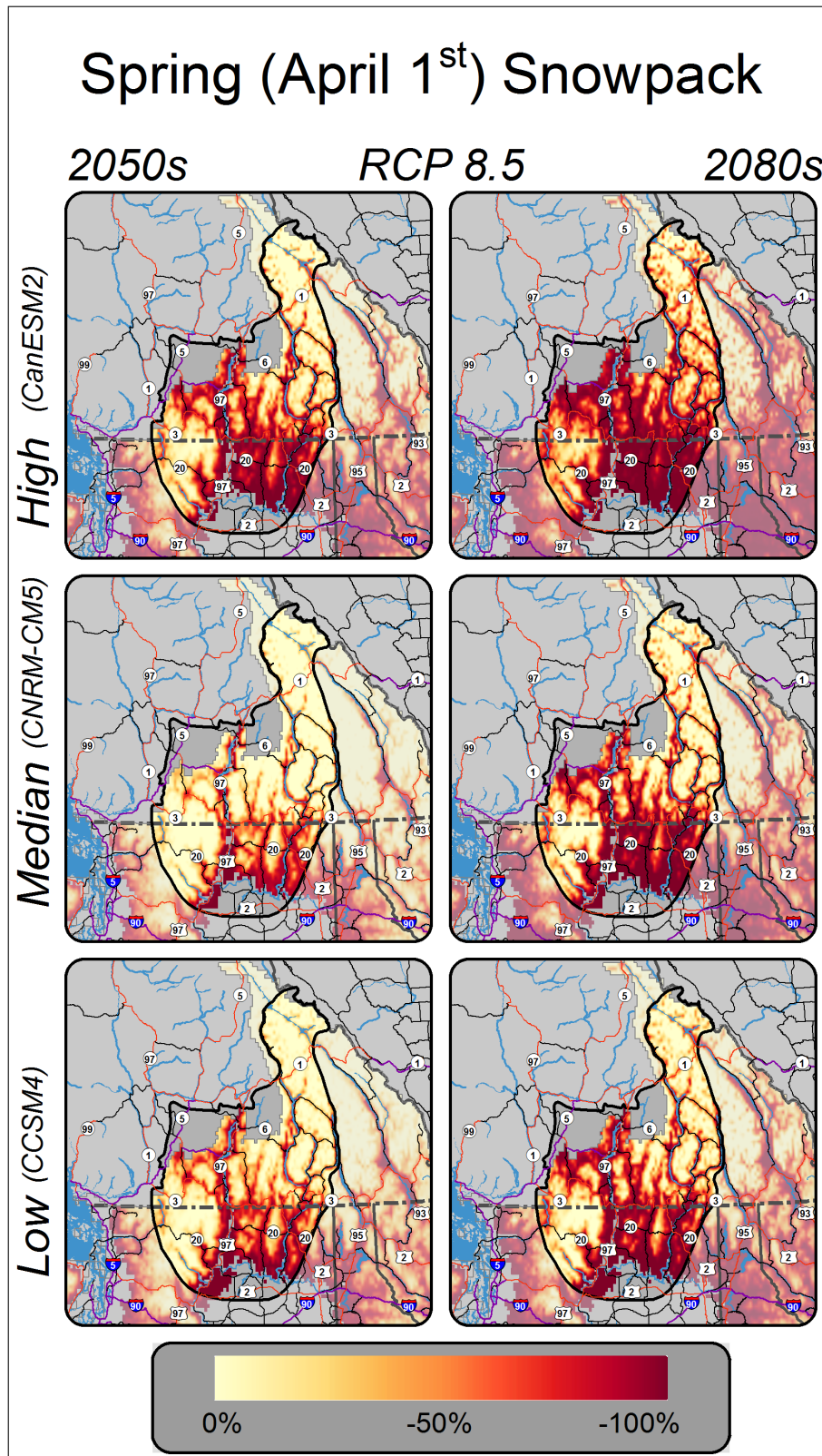
Appendix J.5h. Increase in Average Annual Daytime Temperature

iii) Extent: Washington-British Columbia Transboundary Region



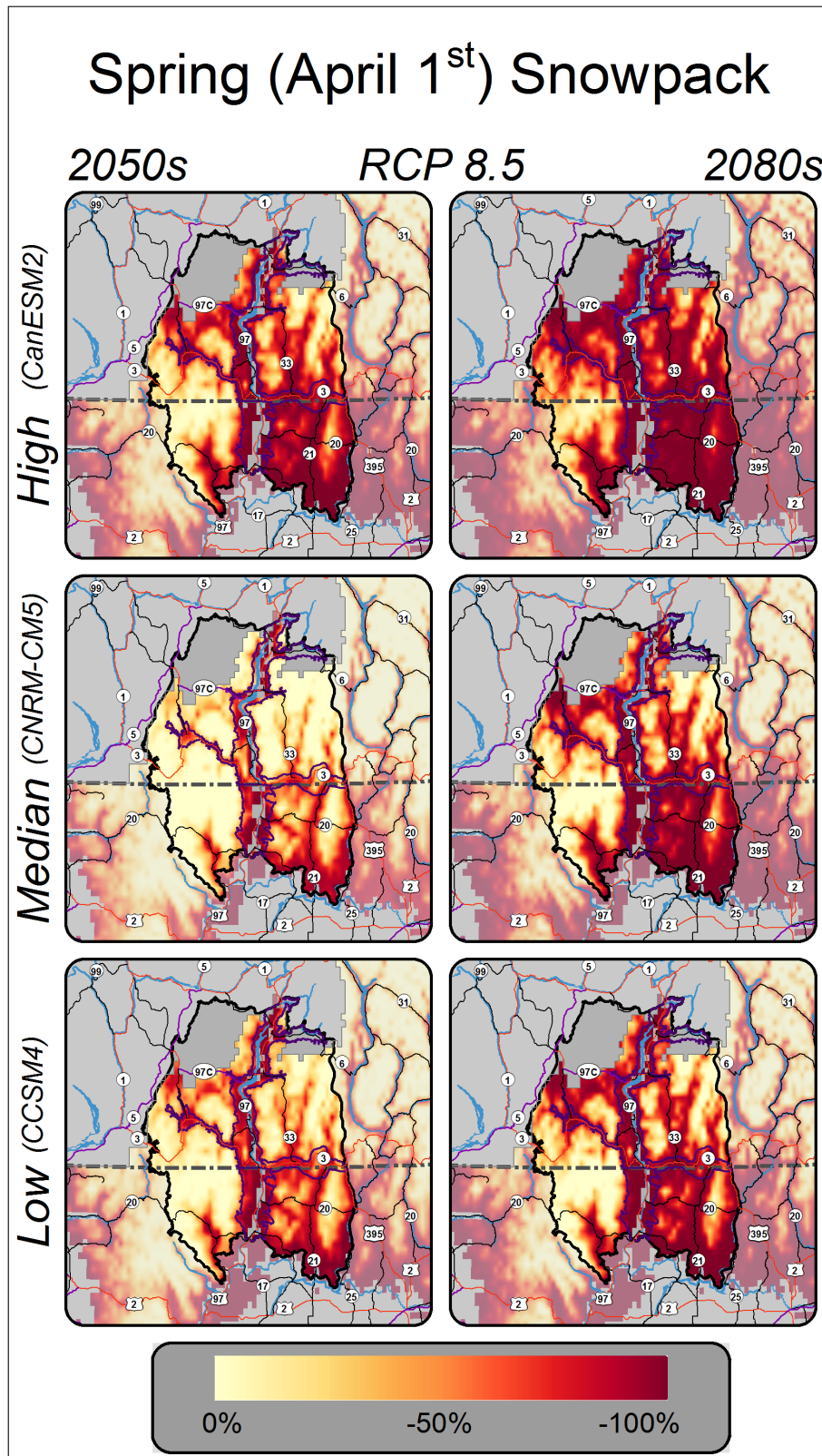
Appendix J.5i. Spring (April 1st) Snowpack

i) Extent: Okanagan Nation Territory



Appendix J.5i. Spring (April 1st) Snowpack

ii) Extent: Okanagan-Kettle Region



Appendix J.5i. Spring (April 1st) Snowpack

iii) Extent: Washington-British Columbia Transboundary Region

